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# Pesticide Externalities, Comparative Advantage, and Commodity Trade

## Cotton in Andhra Pradesh, India

Nalin M. Kishor

Implementing integrated pest management in coastal Andhra Pradesh, India, would reduce not only the external costs but also the private costs of cotton cultivation.

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Because the cotton bollworm is migratory, a farmer who controls the pest in his own field creates a positive externality for other farmers. But because pesticide use leads to the development of pesticide-resistant strains, he also creates a negative externality. These externalities affect a wide range of food crops (notably, coarse grains, pulses, vegetables, and spices) as well as cotton. Because of their extensive (and poorly understood) migratory patterns, pesticide-resistant bollworms are attacking food crops situated hundreds of kilometers from the cotton tracts in coastal Andhra Pradesh, India.

Kishor develops a theoretical model that incorporates these externalities and examines the conditions needed for economically optimal use of pesticides — as well as of other agricultural inputs in cotton cultivation.

Using field data, Kishor tries to quantify the losses in cotton and other crops due to the development of resistant pests. Under one scenario, the costs of externalities could raise the economic cost of cotton cultivation 50 to 60 percent.

After empirically evaluating the taxation of inputs (fertilizer and pesticides) and the implementation of integrated pest management (IPM) practices to address the pest problem, Kishor concludes that IPM (which emphasizes reduced use of pesticides) offers the most feasible and environmentally benign way to achieve Pareto optimality, especially in the long term.

He addresses some problems in making IPM operational, such as providing efficient scouting services. He conjectures that heavy government intervention will be needed if IPM practices are to be successfully adopted by farmers.

Even without IPM, long staple cotton is likely to remain an efficient Indian export. But implementing IPM would substantially reduce not only the external costs but also the private costs of cotton cultivation.

**CONTENTS**

## ACKNOWLEDGMENTS

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I would also like to thank the scientists and officials of ICAR, ICRISAT, PEG-India, ITC and Searle Chemical Industries for sharing their views. Thanks also to the district authorities in Guntur, for cooperating in data collection efforts.

While expressing my gratitude to all of the above, I take full responsibility for the views expressed in this report.

# PESTICIDE EXTERNALITIES, COMPARATIVE ADVANTAGE, AND COMMODITY TRADE: COTTON IN ANDHRA PRADESH, INDIA[1]

## I. INTRODUCTION AND MOTIVATION

Modern agriculture is highly dependent on a large number of chemical inputs such as fertilizers and pesticides. In the initial flush of the technological revolution, we were bowled over by the yield increasing potential of these inputs and their untrammelled use was freely advocated by policy makers. It was visualized that increasing recourse to these inputs was the only way to feed the world's hungry millions. Developments during the last thirty years have, however, made us realise that the use of chemical inputs is not an unmixed blessing. There have been disquieting developments such as contamination of groundwater through leaching of pesticides through the soil, complete crop devastation arising from pest resistance in several parts of the world, soils being made physically and chemically unfit for further cultivation through

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[1] This research has been supported by World Bank RPO# 676-92. The empirical part of this paper is based on a preliminary field visit to Andhra Pradesh, India. Financial support for the visit was provided by FERRO (USDA) and IOPRM. The views expressed in this paper are the author's own and should not be attributed to the World Bank or any of its affiliated agencies. Special thanks to Garry Pursell for sowing the seeds of the idea and for patiently going through several drafts. Thanks also to John English and to Geoff Jackson for their support for this project. I would like to acknowledge the helpful discussions I have had with the participants of the ICAR/IOPRM/USDA Joint Project Development Group Meeting on Managing Insecticide Resistance with Focus on Heliothis Management in India, Hyderabad, India, Oct. 16-17, 1991. The usual disclaimer applies.

excessive use of these inputs, increasing incidence of skin and lung diseases brought on by exposure to these chemicals etc. These developments have made it necessary to take a hard look at the broader consequences of chemical use in agriculture. In general, it is important to take account of the several externalities arising in the process of chemical use in agricultural cultivation. This report includes a preliminary case study which <u>focusses on some of the externalities arising in the process of pesticide use, against the cotton bollworm (Heliothis armigera), in cotton cultivation</u> in the coastal districts of Andhra Pradesh (AP) state in India.

Among the many agricultural crops that are cultivated, both food and non food crops are prone to pest attacks. Some pests are specific to the crop that they attack, such as apple-scab fungus on apples only, brown plant hopper on rice, etc. Other pests are polyphagous, attacking several different agricultural crops indiscriminately. A well known example of a polyphagous pest is the genus Heliothis. Of this, <u>H. armigera, H. zea and H. virescens, are agricultural pests of worldwide significance</u>. Collectively, they are called cotton bollworms and sometimes, "American bollworms", although only H. zea and H. virescens are found in the US.

H. armigera has one of the widest distributions of any agricultural pest, occurring throughout Africa, the Middle East, Southern Europe, the Indian subcontinent, Central and South-East Asia, eastern and northern Australia, New Zealand and many eastern Pacific islands. Since H. zea occurs across the Americas these two species, between them, circle the globe and are therefore one of the foremost agricultural pests in several parts of the world. They are highly polyphagous, attacking a wide variety of crops such as maize, sorghum, sunflower, cotton, tobacco, soyabean, pulses, safflower, rapeseed, groundnuts as well as a number of vegetables (tomato, cabbages, cauliflower and okra) and some fruits. Cotton, tobacco, chillies, soyabean and pulses (primarily pigeonpea and chickpea), which are high value non food crops or staple food crops, account for most of the losses due to Heliothis. Cotton, tobacco, sweetcorn, and horticultural products such as tomatoes and cut flowers receive a disproportionate amount of the total pesticide applied because of their low economic tolerance to the pest. Financial and economic losses, both from direct yield reduction as well as the (otherwise unnecessary) expenditures on pesticides and pest control operations can be especially significant for these crops.

Losses due to these pests may be classified into two categories--continuing losses and catastrophic losses. Thus, estimates of annual damages (due to Heliothis alone) are $300 million, on pigeonpea and chickpea, the two most important legumes in India (Reed and Pawar, 1982). In Tanzania, annual losses on cotton amount to more than $20 million in most years. In Australia, despite skilfull and scientific efforts to control the pest, there are continuing annual losses to the tune of $25 million, primarily on cotton and sorghum. In USA, the continuing annual losses on all crops due to H. zea and H. virescens are estimated to be $1 billion (Fitt, 1989).

Distinct from the continuing losses of the sort mentioned above, but no less important, there have been (not infrequent) situations of a total inability to control pest outbreaks on different crops in different parts of the world, e.g., sunflower in Kenya, cotton in India, Sudan and Egypt, etc. These catastrophic losses (or crop failures) result in severe economic losses which can be especially devastating for the small and financially strapped farmers in these countries. For example, the 1987/88 failure of the cotton crop in some districts of Andhra Pradesh, resulted in a loss of about $150 million and represented about 15% of the total annual agricultural income of the state (see Section VI).

It is clear from the above description that Heliothis is a major pest on both food crops and cash crops in many parts of the world. Specifically, for India, H. armigera is a major pest on cotton, chillies, pulses, sorghum and vegetables (see section VIII). In this study we focus on long staple cotton cultivation in coastal AP, even though H. armigera attacks a wide diversity of other crops. There are two major reasons. The <u>first reason</u> stems from the fact that cotton is the most heavily sprayed crop in the coastal areas of AP and therefore forms the main source of pesticide resistance. The <u>second reason</u> arises from the fact that the long staple cotton grown in AP has been identified as an efficient export crop from India. This merits a more careful look at its production possibilities with a view to assessing its export potential in the medium to long term (Gulati, 1990). We shall elaborate on each of the two reasons in the following subsections.

### Externalities Arising in Cotton Cultivation

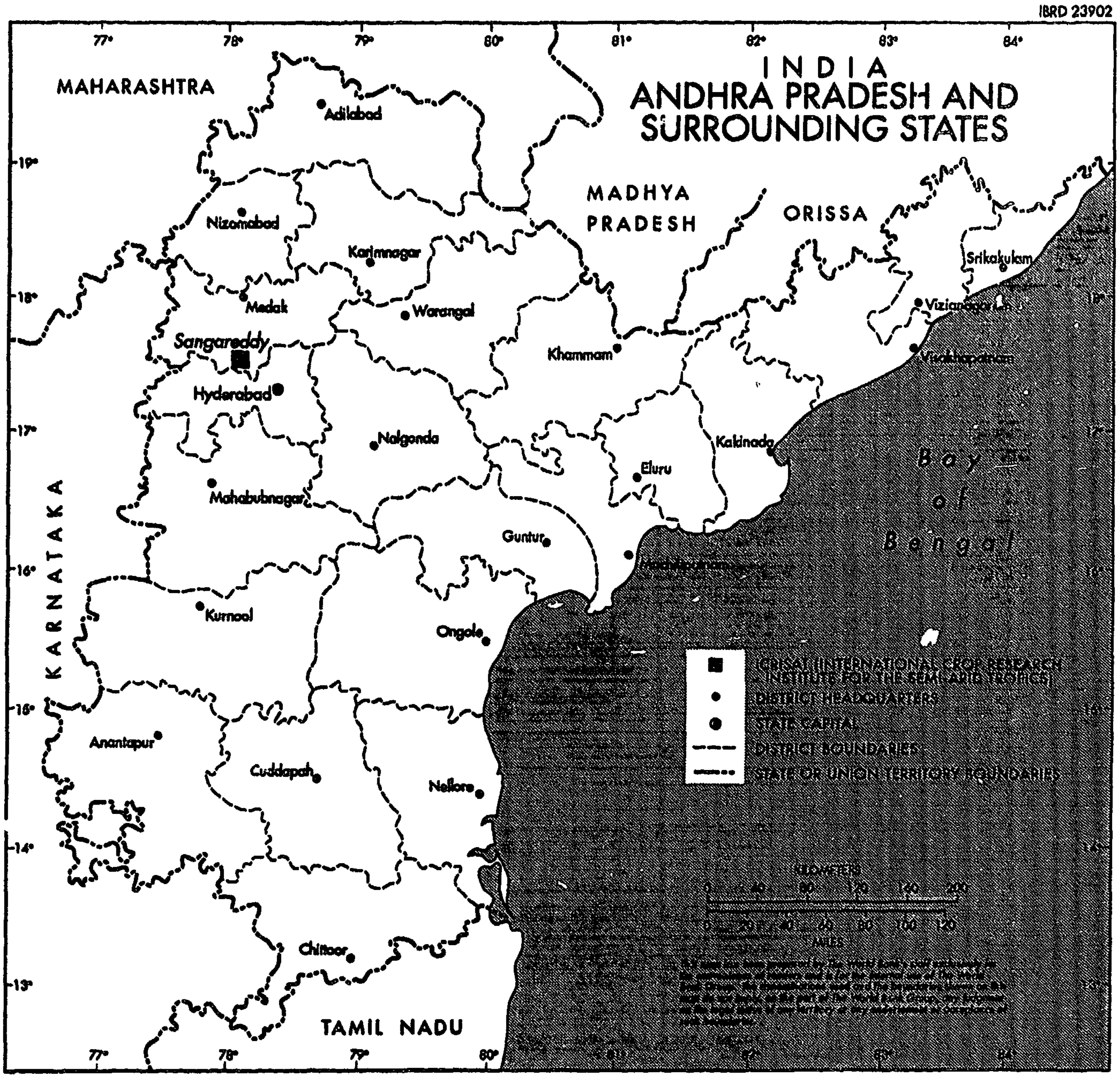
A significant proportion (60-70%) of Indian long staple cotton is grown in AP. Cotton accounts for 5% of the total cultivated area in the state. Out of a total annual acreage of 530,000 ha planted in 1990/91, 200,000 ha were in the coastal districts of Krishna, Prakasam and Guntur. Of this, Guntur alone accounts for 150,000 ha, which forms about 30% of the area under kharif cultivation in the district. (The kharif crop is planted with the onset of the rainy season, between June and August, and harvested between December and February). Cotton is grown primarily as a rainfed (no more than 15% of the area under cotton is usually irrigated in Guntur) monoculture crop, on small farms, the average size of which is less than one hectare. Thus, there are about 250,000 cotton farms in the area. Since cotton is a high value crop the cultivation is extremely pesticide intensive. For the triennium 1979/80 to 1982/83 (at 1970/71 prices), while AP accounted for 17% of the pesticide use on cotton in India, it accounts for only 5.5% of the acreage under cotton. This translates to the highest per hectare use of pesticides in AP, being 30% higher than the level in Gujarat, the next most intensive user (Alagh, 1988). More recent evidence also indicates that this gap has remained almost unchanged. Within the average picture for the state, coastal AP uses 20-30% more pesticides than the state average. In terms of costs, in coastal

AP, pesticides constitute as much as 50-60% of the total costs of cotton cultivation per (unirrigated) hectare.

Some of the commonly used pesticides are: cypermethrin, deltamethrin and fenvalerate, etc. (all of which belong to the Synthetic Pyrethroids, SP, group), endosulfan, monocrotophos, carbaryl, dimethoate, phosphamidon and quinalphos. These pesticides are directed primarily towards the control of the cotton bollworm, Heliothis armigera, to which (as mentioned above) cotton is most susceptible. The SPs, which were introduced in the late 70s, spread rapidly since they were extremely effective, relatively cheap and broad spectrum in their action and soon became the mainstay of the Heliothis control efforts in the area. Since H. armigera is known to undertake extensive local migration (see Section IV), any one farmer's control of the pest on his field will contribute a <u>positive externality</u> to the other farmers in that area. On the other hand, since total pesticide use results in the development of resistant strains, each farmer's use of the pesticide also results in a <u>negative externality</u> to the other farmers in that area. Additionally, available evidence from the Guntur area indicates that the individual farmer is not applying pesticides optimally (especially as regards the application of synthetic pyrethroids), in relation to the technical requirements. Thus, farmers are applying as much as 20-25 sprays as against the 12-14 recommended doses (Murthy, 1991). The excessive application (or collective overuse) also exacerbates the negative externality problem since pest resistance is a direct function of total pesticide used in an area. Evidence for this negative externality is offered by the fact that in the 1987/88 cotton season, there was a complete devastation of the crop in the Krishna and Guntur districts. This was because of a failure to control the cotton bollworm. Subsequent bioassay experiments revealed that this failure arose from the substantial resistance of H. armigera to the SPs being commonly used in that area (McCaffery et al., 1989). In fact, on the basis of available evidence, it is generally agreed that the Guntur area now forms a localized "hot spot", i.e., a reservoir of Heliothis strains, resistant to SPs.

We will now describe how the creation of this "hot spot" in Guntur has led to another sort of externality. Since H. armigera is highly polyphagous we know that it can feed not only on cotton but also on pigeonpea, chickpea, and sorghum as well as some vegetable (cabbage, cauliflower, tomatoes, okra) and on fruit crops. These are major crops in the semi-arid South Eastern parts of India, being grown on the hundreds of thousands of, largely family operated farms in that area. There is evidence (see Section IV) to suggest that in the latter part of the year, from October to December, the Heliothis moths undertake extensive long range migration (helped by the prevailing winds) from the coast to the inland areas of the state. By migrating as much as 250-300 Kms inland, H. armigera has become a major pest of pigeonpea, chickpea, and sorghum, as well as cotton, on the farms around Hyderabad (Refer to Map 1). Samples of H. armigera taken from the pigeonpea and chickpea fields of ICRISAT (International Crop Research

MAP 1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Mahabubnagar
Eluru
Kakinada
Guntur
Kurnool
Ongole
Anantapur
Cuddapah
Nellore
Chittoor
Srikakulam
Vizianagaram
Visakhapatnam
ICRISAT (INTERNATIONAL CROP RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS)
DISTRICT HEADQUARTERS
STATE CAPITAL
DISTRICT BOUNDARIES
STATE OR UNION TERRITORY BOUNDARIES
KILOMETERS
MILES
77° 78° 79° 80° 81° 82° 83° 84°
19° 18° 17° 16° 15° 14° 13°

Institute for the Semi Arid Tropics, Patencheru (AP)), suggest that the resistance to synthetic pyrethroids was not a feature of the bollworms until late 1987 (McCaffery et.al, 1989). It thus seems clear that the pesticide resistant strains have spread from the coastal to the inland areas, creating another serious negative externality, on other crops, in areas quite distant from the "hot spot".

## Cotton as an Efficient Export Crop

The second important reason to focus on cotton is because, based on a comparison of domestic and international prices and subsidy estimates, long staple cotton lint appears to be an efficient export commodity from India. On average, for the eighties, annual cotton exports (valued at about $300m) comprise about 6% of total domestic production. (Imports form about 1% of domestic production on average). However recent studies (Gulati, 1991) and World Bank reports have emphasized that there is scope for increasing the production as well as exports of long staple cotton. This could provide a strong growth impetus to agriculture as well as foreign exchange to the economy. This recommendation is based on a consideration of the direct (paid out) and indirect (imputed) costs of cultivation. However to get the full economic costs of cotton production we must look at the extended costs of cultivation, i.e. factor-in the potential externalities arising in cotton production. This will enable us to more fully address the issue of whether production and export of cotton is economically profitable. (This as well as other related issues will be discussed in more detail in Section X of this report).

To recapitulate: The foregoing discussion has described how Heliothis is a major agricultural pest in India and how efforts to control it in cotton have led to a build up of resistant strains through pesticide misuse and overuse. Furthermore, we have also described how the (natural) polyphagous and migratory traits of Heliothis have combined with the (largely human induced) resistance of the insect, to aggravate the pest status of Heliothis. Clearly, given the objective of environmentally sustainable and economically profitable cotton cultivation, it is essential that we carefully examine the role of pests/pesticides in its cultivation.

To this end, the rest of this report is organized as follows: In Section II we will briefly summarize the existing literature dealing with pest resistance and pesticide externalities in agriculture. The limitations of existing models as regards their applicability to Guntur cotton cultivation will be pointed out and an attempt made to develop a more appropriate model in Section III. Then this theoretical model will be taken through its paces to formalize the several externalities discussed above. Note that because of data limitations and present gaps in knowledge regarding the important variables entering into the various equations empirical estimation of the model will not be attempted at this stage. Nevertheless, the model provides a useful framework for the empirical discussion presented in this report, as well as some insights which are relevant for public policies.

In Sections IV and V, we will discuss the ecology of Heliothis armigera in India, the factors responsible for the development of resistance to pesticides, especially to synthetic pyrethroids and the extent and implications of its migratory potential. This contributes additional lessons for public policy issues. Keeping within the framework of the theoretical model (although without estimating it formally), subsequent sections (VI to X) will focus on preliminary estimates of the magnitude (costs) of the above mentioned externalities and the associated policy implications. Section XI summarizes the report and outlines the empirical research which is necessary to complement the preliminary findings of this report.

## II. RECENT RELEVANT LITERATURE

Existing literature has followed two broad paths--specific attention to pest resistance in an optimal control framework and, a predator-prey relationship focussing on the possibility of primary crop failure due to a secondary pest.

a) A number of papers (Hueth and Regev, 1974, Feder and Regev, 1975, Regev, Shalit and Gutierrez, 1983) have looked at the optimal control of a pest population by constructing a single pest, single crop model. The fact that pest resistance is a function of the total quantity of pesticide application, is an important feature of these models. An objective function is defined as the present discounted value of profits. Then the optimal path of input (pesticide) use is derived by maximizing this function subject to two constraints--a dynamic pesticide resistance equation and a dynamic pest population equation. Three types of alternatives are considered:

i) An optimal control model with alternative technologies including a "backstop" (In this context, a backstop technology is defined to be one that does not increase the pest resistance, in any context.) pest control strategy, to examine the optimal duration of pesticide application before a possible switchover to the alternative technology.

ii) A central planners problem, but with myopia regarding build-up of pest resistance to the pesticide i.e., the central planner is ignorant of the fact that overall pesticide use leads to resistance build-up. Thus maximization of the objective function is subject to only one constraint-the pest population equation.

iii) A competitive farmer's profit maximisation model with the assumption that resistance develops in relation to the total quantity of pesticides applied in a particular farming area containing a very large nnumber of farms. Therefore, the effect that an individual farmer has on resistance build-up and on the level of pest populations is negligible and anyway, beyond his control. In this case, the competitive grower maximizes his individual profit function, taking the initial pest population and initial level of resistance to be exogeneous parameters.

The optimum path of pesticide application and the levels of output and profit are analysed under each of the three situations, (Regev, Shalit and Gutierrez, 1983). Under alternative i), it is found that the optimal policy consists of large initial pesticide applications and smaller quantities towards the end of the planning horizon. This pattern enables the control of the pest population at a low level and is partly the outcome of applying a discount rate to future profits. Furthermore, the switch to the alternative technology is influenced by the assumed rate of discount and the stream of returns associated with the alternative technology of pest control. Under alternative ii), it is found that the total application of pesticides is greater than under i) while profits are smaller. Finally, under alternative iii), as a result of completely ignoring the externality arising from the development of resistance, the competitive grower makes the smallest profits.

While these models contribute valuable insights as regards knowledge of optimal pesticide application schedules, optimal tax schedules to ensure Pareto optimality and the level of pest infestation, they suffer an important limitation in that the role of the backstop (alternative) technology is not given enough consideration. Thus, there is only a single alternative technology which "kicks in" after pesticide resistance has reached a certain "high" level. In reality, there exist significant substitution possibilities (these are better known as Integrated Pest Management, IPM, techniques) between pesticides and non chemical means to control pests and therefore it is not obvious why the farmer should switch to the backstop technology <u>after</u> using only pesticides to control pests initially. Since IPM has an extremely crucial role to play in determining sustainable agricultural development we will describe this strategy in some detail, shortly.

b) The research summarized above has largely ignored the fact that the use of broad spectrum pesticides often leads to outbreaks of secondary pest damage through a predator-prey chain. To elaborate, the secondary pest also damages cotton but is kept under control because of the existence of natural predators which prey largely on the secondary pest. Often these natural predators are much more susceptible to broad spectrum pesticides than their prey. Once their natural enemies are destroyed, secondary pests increase rapidly and can wreak severe damage on the crop. Harper and Zilberman (Harper and Zilberman, 1989) explicitly take account of the predator-prey relationship. Their model is then applied to cotton for the Imperial Valley in California for the years 1964-1980. It is found that secondary pest damage is as much as 94% of pink bollworm (primary pest) damage, on average. These results indicate that the possibility of secondary pest damage must not be ignored. Empirically, in the case of Guntur cotton cultivation, this aspect is likely to be unimportant (ICRISAT, ICAR entomologists, pers. com.). Thus, while recognizing that this aspect could be important in some situations, it is ignored in the present analysis.

A common criticism against both the above mentioned lines of research is that they assume that the pest management system being considered is a compact region, closed to external pest migration.

We have already discussed how, due to the fact that it migrates several hundred kilometers inland (and due to the fact that it is polyphagous), the cotton bollworm imposes a negative externality on other crops in the Guntur area and on all crops including cotton in distant areas. Hence for our model to be realistic, it must incorporate an external damage function to take account of this negative externality.

## The Integrated Pest Management Approach

The most important alternative to the purely chemical control of pests, goes under the acronym, IPM which stands for, Integrated Pest Management (Flint and Bosch, 1982, Metcalf and Luckmann, 1982, Dover, 1985). As the name suggests, this strategy takes a holistic view of agricultural production and tries to minimize the use of chemical pesticides by exploiting the trade-off or substitution between chemical inputs and "natural" inputs. In general, the IPM strategy relies upon reduction of pesticide use (to minimize the build-up of resistance) through careful monitoring (scouting) of pest populations, manual picking of eggs/larvae, encouragement of the natural predator population, thinning of cotton plants and use of plant growth regulators to reduce the pest carrying capacity of the crop, regulating the time of planting and harvesting and a host of other measures. It thus emphasises agronomic practices which are environmentally the least inimical and the most sustainable in the long run. Specific components of IPM in the case of cotton will be mentioned in later sections but a typical problem is briefly mentioned here. It deals with the choice between a long growing season, $X_1$, versus a shorter growing season, $X_2$, with the quantity of pesticide at some predetermined level in either situation (Harper and Zilberman, 1989). If the maximum pest population, $k_1(X_c)$, is written as the product of an exogenous level of pest pressure, K, and a pest stimulus effect, $\psi(X_c)$, then the first order condition (FOC) which will determine the choice of X is as follows:

If

$$\begin{aligned} &P_c f_c(X_1)\ (1 - D[K\psi(X_1)[1 - g_1(Z_1)]]) - C(X_1) \\ &> P_c f_c(X_2)\ (1 - D[K\psi(X_2)[1 - g_1(Z_1)]]) - C(X_2) \end{aligned} \tag{1}$$

then choose X = $X_1$, otherwise choose $X_2$. Note that C(.) refers to the costs of cultivation, Z refers to the application of pesticide and the g(z) function gives the fraction of pests killed via application of pesticides.

The main message from this comparison is that although the potential yield is higher for the longer growing season, so is the pest population and so is the percentage of the potential yield lost through damage. As the preexisting level of pest pressure, K, increases, a threshold level of K will be reached above which the optimal growing season switches from long to short. Myopic pest management, based on chemical control alone, will fail to perceive this.

In a similar manner, the timing of pesticide application is as important as the quantity of pesticide used. Thus within the context of IPM, the pest population is carefully monitored in each part of the field. It is believed that only above a critical level is it necessary to control the pest population from becoming too destructive. This is better known as the Economic Threshold Level or ETL. An ETL is defined to be the pest density, as say, a certain number of larvae per plant, above which the marginal return from preventing crop damage is greater than the marginal cost of pesticides used. Yield damage experiments have been able to identify this threshold and again it is important to incorporate this information in formulating an optimal policy of cotton cultivation. Feder and Regev (Feder and Regev, 1975) have pointed out another aspect of the timing decision. They argue that migrant pests can reinfest the cotton farms several times during each growing season. This is because it is the total population of pests in a region that determines the pest infestation on individual farms, once the effects of a pesticide application has worn off. Thus, for pesticide application to be socially optimal requires that all farmers in a region apply pesticides at the same time. Clearly, this has important implications in the design of policy.

## III. THE BASIC THEORETICAL MODEL

Based on the foregoing discussion, a realistic model of pesticide use in cotton (for the Guntur area) must incorporate the following key aspects:

i) Positive externalies arising from an individual farmer's control of the primary pest on his field.

ii) Negative externalities within cotton, arising from the build-up of pest resistance.

iii) Negative externalities arising due to the migration of resistant pests, resulting in damage to non cotton crops in the Guntur area as well as to cotton and other susceptible crops in the more distant areas.

iv) An explicit consideration of Integrated Pest Management strategies.

An important issue which must be resolved is, what should be the length of a farmer's (and the social planner's) planning horizon? Bioassay experiments have clearly shown that the build up of pest resistance takes place over several generations of pests. Evidence collected by entomologists indicates that as many as five generations of H. armigera can complete their life cycle in a single cotton growing season (as many as eight in Punjab, ICRISAT Symposium volume, 1981). Furthermore, the current season's level of resistance of the pests will depend upon the previous season's total "stock" of resistant pests. Thus to get the true social optimum, the model must be solved as a multiperiod one giving explicit consideration to the inter generational build up of pest resistance. However, in this report, we will assume that the build up of resistance is instantaneous. Thus, the socially optimum values will be derived in a static, one period optimization framework. (Note that this is an approximation to the real world situation. To the extent that optimal control models are formulated in continuous time, they seem to do a better job of modelling the decision making process.). Some justification for this approach arises from the fact that, as claimed above, resistant strains can build up quite fast, within a season. But the major justification arises from the need to keep the exposition simple so as to better highlight the main results.

The algebraic equations describing the key relationships as well as the proposed simplifications will be spelt out next. Following that, we will focus on the model solutions. The model will be solved from specific to most general, i.e., we will first incorporate the negative externality aspect on "other crops", then the negative externality arising in cotton due to resistance build-up and finally the positive externality in cotton due to individual control of pests. At each stage the model will be solved under two different assumptions--individual profit maximization with no knowledge/concern of the relevant externality(ies), and centralized decision making with knowledge of the relevant externality(ies). The centralized model is a heuristic approach for obtaining the Pareto optimal solution, and a comparison of these two solutions at each stage will give us an extent of the social inoptimalities involved in pesticide application.

The model consists of the functional relationships described in the next few subsections, all of which have to be empirically estimated. Before we go on to a description of these equations, the reader is again cautioned that estimation of the theoretical model requires an extensive data base. Because this data is unavailable at the present moment we cannot estimate the full-blown model. However, to reiterate, the model serves two important purposes. First, the prescriptions coming out of the model have extremely important real world policy implications. (Readers not wishing to work through the mathematics can go directly to the last two subsections of Section III). Secondly, the model provides a framework within which to carry out the preliminary empirical work of the later sections.

<u>Cotton Production Function</u>

Cotton production is stylized by the following equation:

$$Q_{ci} = f_{ci}(X_{ci})\,[1-D_{ci}(\boldsymbol{S}_i)] \tag{2}$$

where "i" indexes the N cotton farmers, $Q_c$ is the net output of cotton, $X_c$ is a vector of primary inputs such as water, fertilizer etc. To simplify, we will consider only one primary input, say fertilizer. The cotton production function, $f_c$ is concave with the first derivative positive and a negative second derivative.

$D_c(S)$ is the cotton damage function, expressing the fraction of yield which is lost through pests. In general $S$ can have two elements, a primary pest, $S_1$ and a secondary pest, $S_2$. As stated earlier, we will take only the primary pest, $S_1$. From dose-response function studies, $D_c$ typically has the following form:

$$D_{ci} = 1 - e^{-\beta_{1i} S_{1i}} \tag{3}$$

The shape of the damage function is described in Figure 1.

We have not taken explicit account of uncertainty in the production function. Again, this is done to keep the algebra simple. Since uncertainty plays an important role in the demand for pesticides (Feder, 1979, Pannell, 1991) its role will be discussed briefly in the concluding section of this report.

## Pest Population Equation

Primary pest equation

$$S_{1i} = k_{1i}(X_{ci})\,[1-g_{1i}(Z_{1i})] \tag{3}$$

where $k_1(.)$ represents the carrying capacity of pests of the cotton crop, and, in this specification, depends upon the amount of the primary input used. $Z_1$ is the pesticide used and, $g_1$ is the kill function for the pesticide. Again, it must be emphasised that equation (3) is a simplified representation of reality since the

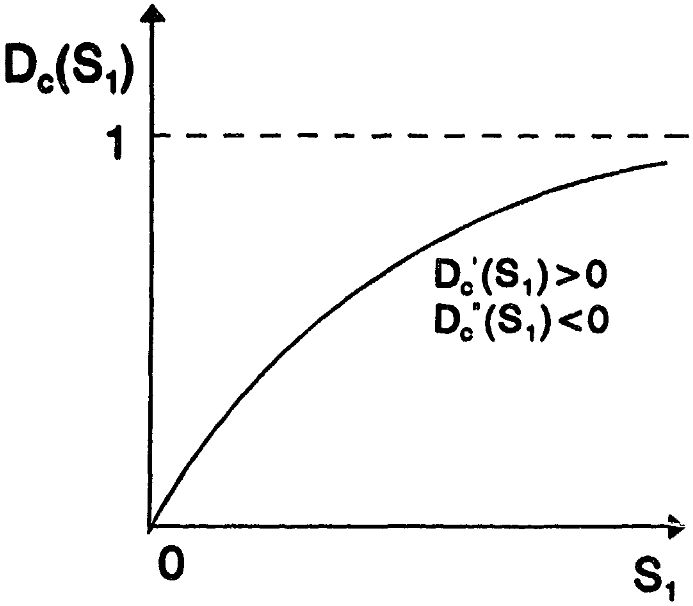


FIGURE 1

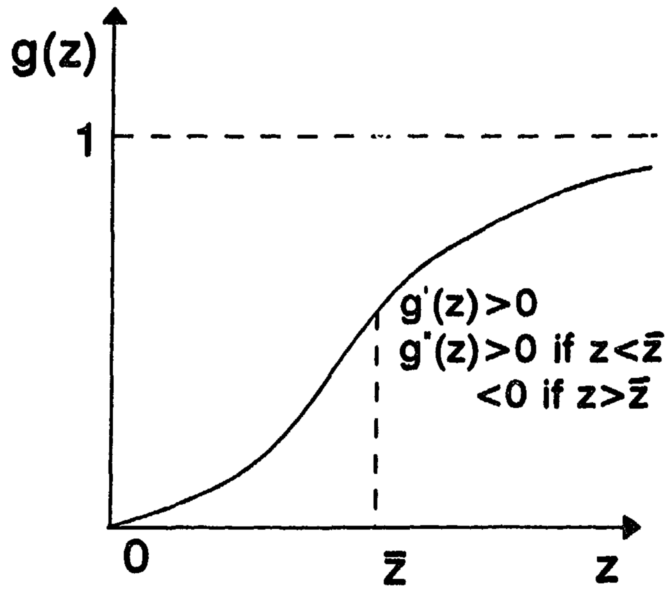


FIGURE 2

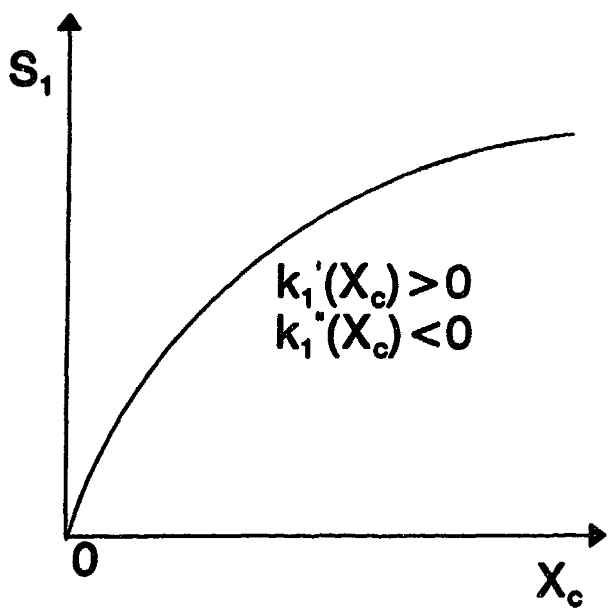


FIGURE 3

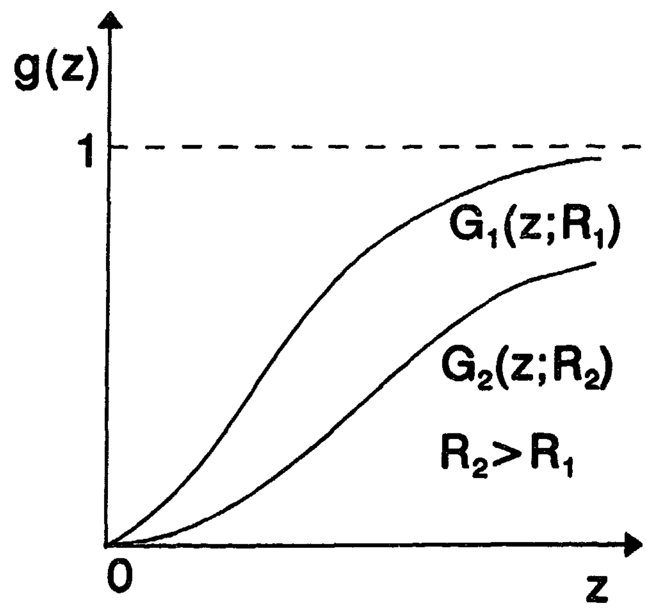


FIGURE 4

carrying capacity will also be affected by factors such as temperature and humidity. Econometric estimation of these relationships will naturally have to consider these variables. Figures 2 and 3 illustrate the shapes of the kill function and carrying capacity functions respectively.

External Damage Function

The damage that H. armigera inflicts on other crops will be accounted for by the "other-crops" damage function, $D_p$, so that net output is given by:

$$Q_p = f_c(X_p)\,[\,1-D_p(S_T)\,] \tag{5}$$

Again, to keep the exposition simple, we have assumed initially that there is an aggregate "other crops" damage function and that the "other-crops" farmers do not take preventive action against the pest. The variable $S_T$, in the damage function is the total of $S_{it}$'s of all the cotton farmers. (The general case, where there are "M" "other-crop" farmers, each of whom can take preventive action by spraying pesticides, is dealt with in an Appendix--available from the author upon request). It is assumed that $D_p$, the damage function, can be characterized (similar to $D_c$) as follows:

$$D_p = 1-e^{-\beta_2 S_T} \tag{6}$$

Model Solution

Let $P_c$ be the price of cotton and $P_p$ the price of "other crops" on which H. armigera feeds.

a) Negative externality on "other-crops".

Initially it is assumed that we are dealing with N cotton farmers with their respective production and cost functions and a single (composite) other-crops farmer. Thus, we first look at the central planner's problem, which is solved by considering the profit maximisation for the typical cotton farmer, say #1, who is assumed to take into account the externality on other crops. The profit maximisation exercise is:

$$Max.\ \pi_{c1}[X_{c1}, X_p, Z_{11}] = P_c f_{c1}(X_{c1})[1-D_{c1}(S_{11})] + P_p f_p(X_p)[1-D_p(S_T)] - w_1 Z_{11} - w_2(X_{c1}+X_p) \tag{7}$$

Subject to:

$$S_{1i} = k_{1i}(X_{ci})[1-g_{1i}(Z_{1i})] \tag{8}$$

where "i" runs from 1 to N, and

$$\pi_{cj} \geq \pi^*_{cj}, j = 2, \ldots, N. \tag{9}$$

The associated Lagrangian is then:

$$L = P_{c1}f_{c1}(X_{c1})\,[\,1-D_{c1}(S_{11})\,] + P_p f_p(X_p)\,[\,1-D_p(S_T)\,]$$
$$- W_1 Z_{11} - W_2 X_1 + \sum_{i=1}^{N} \lambda_i [S_{1i} - k_{1i}(X_{ci})\,[\,1-g_{1i}(Z_{1i})\,]\,] \tag{10}$$
$$+ \sum_{j=2}^{N} \sigma_j [\pi^*_{cj} - \pi_{cj}]$$

For an interior maximum, the first order conditions for this problem are:

$$\frac{\delta L}{\delta X_{c1}} = P_c f'_{c1}(X_{c1})\,[\,1-D_{c1}(S_{11})\,] - W_2 - \lambda_1 k'_{11}(X_{c1})\,[\,1-g_{11}(Z_{11})\,] = 0 \tag{11}$$

$$\frac{\delta L}{\delta X_p} = P_p f_p'(X_p)\,[\,1-D_p(S_T)\,] - W_2 = 0 \tag{12}$$

$$\frac{\delta L}{\delta Z_{11}} = -W_1 + \lambda_1 k_{11}(X_{c1})\,g'_{11}(Z_{11}) = 0 \tag{13}$$

$$\frac{\delta L}{\delta \lambda_1} = S_{11} - k_{11}(X_{c1})\,[\,1-g_{11}(Z_{11})\,] = 0 \tag{14}$$

$$\frac{\delta L}{\delta S_{11}} = - P_c f_{c1}(X_{c1}) D'_{c1}(S_{11}) - P_p f_p(X_p) D_p'(S_T) + \lambda_1 = 0 \qquad (15)$$

From equation (15):

$$\lambda_1 = P_c f_{c1}(X_{c1}) D'_{c1}(S_{11}) + P_p f_p(X_p) D_p'(S_T) \qquad (16)$$

From (16), it is clear that $\lambda_1$ measures the shadow price or social cost of a marginal change in the pest population. This cost is a weighted average of the direct damage to cotton and the indirect (externality) damage to the rest of the crops.

By rearranging equation (11), we get the following optimality condition:

$$P_c f'_{c1}(X_{c1}) [ 1- D_{c1}(S_{11}) ] = W_2 + \lambda_1 k'_{11}(X_{c1}) [ 1- g_{11}(Z_{11}) ] \qquad (17)$$

Equation (17) states that the basic input $X_c$ will be applied upto the point where its marginal benefit, as measured by the LHS of equation (17), is equal to its marginal market cost, $W_2$, <u>plus</u> the marginal cost arising due to the damage inflicted by the pest population.

If the externality aspect were not taken into account i.e. we were dealing with the individual profit maximising farmer, then the value of the Lagrangian multiplier, say $\mu_1$ would be given by:

$$\mu_1 = P_c f_{c1}(X_{c1}) D'_{c1}(S_{11}) \qquad (18)$$

i.e. the farmer will not take account of the damage done to the other crops. In this case the profit maximising condition for the primary input becomes:

$$P_c f'_{c1}(X_{c1}) [\, 1 - D_{c1}(S_{11})\,] = W_2 + \mu_1 k'_{11}(X_{c1}) [\, 1 - g_{11}(Z_{11})\,] \qquad (19)$$

Given that the damage to the other crops is some nonzero amount, $\mu_1$ is smaller than $\lambda_1$ for any level of $X_c$ (compare equation (18) with equation (16)). Further, since all the first derivatives in equation (19) are positive and the second derivatives of the production function and the carrying capacity function are negative, ignoring the externality results in <u>over-application</u> of the primary input, $X_c$.

Equation (12) states the standard, "price equals marginal cost" relationship for the primary input into other crops.

Similarly, equation (13) states the marginal condition for pesticide use. It can be rearranged as:

$$W_1 = \lambda_1 k_{11}(X_{c1}) g'_{11}(Z_{11}) \qquad (20)$$

If the externality is ignored, then the optimal condition is given by:

$$W_1 = \mu_1 k_{11}(\hat{X}_{c1}) g'_{11}(Z_{11}) \tag{21}$$

A comparison of (21) with (20) shows that if the farmer ignores externalities, then the use of the pesticide will be inoptimal. Whether pesticide use will be excessive or sub optimal depends upon the shapes of the carrying capacity and kill functions. In comparing equations (20) and (21), we know that $\mu_1$ is smaller than $\lambda_1$ but $k_{11}(\hat{X}_{c1})$ is greater than $k_{11}(X_{c1})$, since $\hat{X}_c$ is greater than $X_c$. If $\lambda_1 k(X_{c\cdot})$ is greater than $\mu_1 k_{11}(\hat{X}_{c1})$, (as is most likely the case, since the external damage is likely to be large while the carrying capacity function for an individual farmer will rise quite gradually), <u>and</u> the farmer is on the (upper) flatter portion of the kill function, then this model would indicate that pesticide use is suboptimal.

The preceding profit maximisation exercise brings into focus, two major results. The first result states that, ignoring the externality will lead to a suboptimal application of the pesticide. This makes intuitive sense, because the individual farmer by ignoring the externality also ignores the beneficiant effects of his use of pesticides on the other crops.(Remember, however that this result is subject to empirical verification, since theoretically it can go either way).

The second result states that there will be an inoptimality in the use of the primary input. More specifically, once we incorporate the negative externality on other crops into the model, optimality requires that there be a less intensive cultivation of cotton. Intuitively, this arises from the assumption that the pest population is dependent on the amount of the primary input into cotton production, as stylized by a carrying capacity function. (As a matter of fact, excessive use of fertilizers, especially nitrogenous, results in excessively bushy plants which make it more attractive for Heliothis.)

In the above model we have assumed that the derivative of the pest carrying capacity function is positive. This implies a cutback in cotton cultivation for the Pareto optimal solution. But in the case where this derivative is negative, the opposite result will hold. (Note, a negative derivative implies that an increase in the input leads to an increase in output <u>and</u> a fall in the pest carrying capacity. For example, increasing the use of growth hormones will make the cotton plant less attractive to the pest.)

Within the framework of the present model, how can optimality in input use be achieved? A comparison of equations (16) and (18) makes it clear that if the values of $\lambda_1$ and $\mu_1$ can be made equal, the individual farmer's maximization will be identical to the social optimum. This can be achieved by imposing a uniform per unit tax equal to $P_p f_p(X_p) D_p'(S_T)$, on $S_{1i}$, the primary pest population on each farmer's field. The solution depends on the assumption that the derivative of the $D_p$ function is identical for all cotton farmers. In other words, each cotton farmer's pest population inflicts the same damage at the margin on the other crops. This seems to be a reasonable assumption since, as a group, the cotton farms are spatially quite separate from the other crops. However, if evidence indicated that the marginal damage for each cotton farmer were different, then the first best solution would have to take this into account and the uniform tax proposed above would be no better than a second best solution. Note also that since it is quite infeasible to count the pest population on each farmers field, a second best approach would be to tax, say that primary input into cotton production which is likely to be highly correlated with the pest population. An alternative (and policy relevant) interpretation of the need to "tax" the pest population, is offered in a following subsection.

The above discussion has also shown that our results are sensitive to the shape of the functional relationships in the model. Clearly, this underscores the need to carefully estimate these relationships ( Lichtenberg and Zilberman, 1986).

b) Build-up of Pesticide Resistant Strains.

So far the model has been based on the assumption that the resistance of pests to the pesticide is independent of the total quantity of pesticides used in a specific region. This is clearly not true since it is well documented that crop pests are migratory and resistance is highly dependent on the total amount of pesticide used in a local area. In other words, each farmer's pesticide use generates externalities for the others, in that area. How do we incorporate the collective nature of this externality into the model? One reasonable way to do it is by respecifying the, "kill function", to include an index of resistance, R, which depends upon the total quantity of pesticide used in the region. Thus, the higher the value of R, the greater is the resistance of the pests and the less effective the pesticide. In algebraic terms, the kill function is redefined as:

$$G_{1i} = g_{1i}(Z_{1i};R) \tag{22}$$

The kill function shifts down, i.e. pesticide application becomes less effective for an individual farmer, as the total quantity of pesticide used in an area goes up. This is illustrated in Fig. 4.

The index of resistance, R, is a function of the total level of pesticide used by each farmer, i.e.

$$R = r(\textstyle\sum_{i=1}^{N} Z_{1i}) \tag{23}$$

With this modification, equation (13) becomes:

$$\frac{\delta L}{\delta Z_{11}} = -W_1 + \lambda_1 k_{11}(X_{c1})\left[\frac{\delta g_{11}}{\delta Z_{11}} + \textstyle\sum_{i=1}^{N} \frac{\delta g_{1i}}{\delta R}\frac{\delta R}{\delta Z_{11}}\right] = 0 \tag{24}$$

where the subscript i indexes the $i^{th}$ farmer and the summation takes account of the total externalities imposed by the $i^{th}$ farmer. Rearranging equation (24), we get:

$$W_1 = \lambda_1 k_{11}(X_{c1}) \left[ \frac{\delta g_{11}}{\delta Z_{11}} + \sum_{i=1}^{N} \frac{\delta g_{1i}}{\delta R} \frac{\delta R}{\delta Z_{11}} \right] \tag{25}$$

Since the derivative of $g_1$ with respect to R is negative and that of R with respect to $Z_{11}$ is positive, a comparison of equation (20) with (25), shows that the socially optimum level of pesticide application has to be less than the actual usage obtaining when this externality is ignored. This is intuitively what we would expect to happen in case a negative externality is ignored.

What are the implications for policy? In this situation of two externalities, Pareto optimality can be achieved by the imposition of two types of taxes. First, as in the previous section there has to be a uniform per unit tax on $S_1$. But in addition, there has to be a uniform per unit tax of $\lambda_1 k_{11}(X_{c1})\sum_{i=1}^{N}(\delta g_{1i}/\delta R)(\delta R/\delta Z_{1i})$ on pesticide input. It is important to note that this prescription is valid only if the derivative of R with respect to $Z_1$ is the same for all farmers, i.e., if all cotton farmers contribute an identical marginal amount to resistance build-up. This may not be a reasonable assumption since the location of a farm would be hypothesised to influence the impact. For example, fringe farms would contribute less to the build-up of resistance per unit of pesticide used. In this situation, a first best solution would be to levy individual taxes based on the location of each farm. Since this is infeasible in practice, imposition of uniform taxes is no better than a second best solution, unless of course each farmer contribution to resistance build-up is identical. (Again, refer to a later subsection for a policy oriented interpretation.)

c) Positive Externalities within Cotton.

It was pointed out in one of the earlier sections that each farmer's use of the pesticide confers a positive externality on other farmers through the destruction of the migrant pests. We will not crank through the modified equilibrium conditions (which incorporate this aspect) but it is clear that if the farmer ignores this externality, his use of the pesticide will be less than the socially optimum level and appropriate corrective action is called for.

The above discussion, has been based on the results of our theoretical model which has been derived under the simplifying assumptions of one aggregate external ("other crops') damage function and no defensive action by the other crop farmer. The results of a more general model with a large number of non-identical cotton farmers as well as a large number of non-identical "other crops" farmers (who also spray pesticides and who also suffer from the development of more resistant strains), have been derived in an appendix (Appendix available from the author upon request). This model shows that the basic policy results remain unchanged, viz. externalities result in inoptimal use of inputs

(Specifically, note that if non cotton farmers also suffer from resistant strains, then pesticide use in cotton is excessive and needs to be curtailed. As will be seen later, this external cost is quite large in the context of the present study.) and a first best solution to achieve Pareto optimality is too complicated to be practical. Thus, in a second best framework, a uniform tax has to be imposed both on a major determinant of the pest population (say a primary input) as well as the pesticide input of each cotton farmer to move towards the socially optimum levels of input use.

## An Alternative Interpretation of the Optimality Conditions: A Justification for Using IPM Techniques.

The analysis presented above has highlighted two sources of divergence between private maximum and social optimum. In essence, it is required that we reduce the consumption of pesticides, Z, and the total pest population in cotton farming, $S_T$. As stated earlier, a reduction in pesticide use can be achieved by imposing a per unit tax on pesticides. Clearly the success of this strategy depends upon the elasticity of demand for pesticides. If demand is inelastic (as is thought to be the situation in Guntur), then raising pesticide prices will not discourage consumption significantly. Thus, as opposed to a short term strategy of raising pesticide prices, a sustainable, long term option would be to reduce the demand for pesticides by shifting the demand curve inwards. How this is to be achieved, we will get to in a moment.

To bring $S_T$ in line with the Pareto optimal level, it was earlier proposed that a direct tax on the pest population on each farmer be imposed. Such a tax is hardly realistic and the alternative proposal was to tax, say fertilizer application, an input that is thought to be highly positively correlated with the pest population. Within the framework of the present model this will be a second best solution. However, keeping in mind the earlier discussion on IPM techniques, it is clear that promoting an IPM package will directly control the pest population, thus making it into a potential first best candidate. Hence, the optimality conditions of our model can be interpreted as providing a strong justification for the adoption of IPM techniques in cotton cultivation. It may be pointed out that adoption of IPM techniques will also reduce the demand for pesticides by shifting the demand curve inwards.

## Summary

In this section we have modelled the implications of two major externalities arising in cotton cultivation--the first because of the migration of pests to other areas and other crops, and the second because of the build up of pesticide resistant strains of pests.

Within the framework of the model presented in this paper, it is shown how the inoptimalities can be internalised through the use of public policy. Thus, it appears that the adoption of IPM practices by farmers together with a tax on pesticides may best address the externality problems. It is further pointed out that adoption of IPM also leads to a reduction in pesticide use by shifting the demand curve for pesticides inwards. Thus, from the point of view of long term sustainability of cotton cultivation, adoption of IPM techniques is crucial. To be sure this is not a surprising result, IPM being advocated by agricultural scientists for some time now. However it is reassuring to see that a simple economic model is consistent with the approach proposed by the agriculturists. Thus, at least to this extent, the algebraic analysis serves a useful purpose.

## IV. THE ECOLOGY OF HELIOTHIS ARMIGERA (HELICOVERPA HUBNER) IN RELATION TO AGRO-ECOSYSTEMS, WITH SPECIAL REFERENCE TO INDIA

In the introductory section, we have briefly touched upon the pest status of H. armigera. In this section we take a more detailed look at the several special characteristics and adaptive abilities of H. armigera which have made it into one of the foremost agricultural pests in several parts of the world including India.

Each of the following subsections will begin with a general discussion and will then focus on the evidence available for India, especially for the Guntur area. This information, as we will see, contributes insights into formulating a strategy for management of the pest. Additionally, the discussion will identify the gaps in our present knowledge and focus on potentially useful research areas.

Broadly speaking, the major pest status of H. armigera arises from four physiological, behavioural and ecological characteristics, that enable it to survive and colonise hostile environments and to exploit agro-ecosystems successfully (Fitt, 1989). These four factors may be classified as--polyphagy, high mobility, high fecundity and facultative diapause.

Polyphagy: All Heliothis spp. are highly polyphagous, attacking a wide range of plant species in many plant families. On a world wide scale, H. armigera has been recorded on at least 60 cultivated and 67 wild host plants. In addition to the crops mentioned earlier, in India, armigera is also a pest of mung beans, capsicums, cabbages and cauliflower. The importance of polyphagy to the population dynamics and pest status of H. armigera is threefold. First, the pest population may develop simultaneously on a number of hosts within a region. Second, populations may develop continuously, by successively exploiting cultivated and uncultivated crops during the year. Third, populations can persist at low densities in seemingly unsuitable areas, to explode on a preferred host as and when the latter is cultivated. For example, in Andhra Pradesh, there is a low population during the summer months on okra, eggplant, tomato and uncultivated hosts (weeds), which migrates onto cotton and multiplies rapidly there once cotton reaches its full vegetative stage by August.

In terms of host selection, there is a strong preference by the pest for the flowering stage of the hosts. All species readily attack legumes but H. armigera attacks maize and sorghum preferentially over most other crops. Note that cotton is not the preferred host of armigera and in many areas cotton is attacked only after alternative (preferred) hosts have senesced (i.e. have developed past the full-blooming stage).

Mobility: The ability to undertake extensive local and interregional movements is the second important factor resulting in armigera becoming a major agricultural pest. H. armigera is a facultative migrant i.e. it migrates in response to poor local conditions for reproduction (shortage of adult nectar sources or oviposition sites) and the occurrence of weather systems conducive to such movement. There is extensive evidence of substantial wind assisted movement by H. armigera. Pedgley (Pedgley, 1985) has shown that armigera migrates upto 1000 kms to reach Britain and other parts of Europe, from sources in southern Europe and North Africa. Evidence from cotton in the Sudan Gezira also suggests considerable mobility of armigera within the irrigated tract.

There is considerable circumstantial evidence from India to indicate widespread migration of the pest. Using light trap catches at ICRISAT for the period 1977-1983, Pedgley et al. (Pedgley et al., 1987) find that catches rise to a maximum in August-September as well as in November-December whence they exhibit a larger maximum. After controlling for the local cropping practices, it is concluded that the August-September peak is most likely due to migration of moths from the coastal and hilly parts of western Maharashtra assisted by the persistent western winds. In fact it is believed that the moths could have reached ICRISAT in three to four nights. Similarly, the November-December peak coincides with the migration of moths from the coastal cotton growing areas of Andhra Pradesh, being helped by the "November winds", blowing from the North-East to East (refer to Maps 1 and 2)[2]. Recent evidence from resistance monitoring studies (Armes et al.,1991) provides further support for this pattern of migration. Thus, it is found that the resistance of Heliothis to synthetic pyrethroids goes down between July-August and is probably due to a dilution of resistance arising from a mixing of susceptible moths migrating from the Maharashtra areas. Further, it is found that by November-December, resistance at ICRISAT mirrors that of the Guntur area. Clearly, this is most likely the result of the migration of moths from Guntur, inland with the "November winds".

The patterns of Heliothis moth migration mentioned above have important implications for a pest control strategy. We shall fill in details later but at this point it is important to realise that a pest control strategy (in the framework of sustainable agricultural development) cannot be successful if it addresses only one crop or even one geographically contiguous area. It has to go beyond and consider the problem in an integrated farming systems framework (Dover, 1985, Dixon, 1989).

One qualifying remark before we address other issues. At present there is little information on aspects of migration such as (i) the proportion of any emerging population of Heliothis that may

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[2] In Map 2, the conical shaded area is termed a "back track" and refers to the migration path for moths, deduced on the basis of moth catches at ICRISAT and on the prevailing wind patterns.

undertake long range as opposed to local migratory movements, (ii) what factors induce the newly emerged adults to move and when and (iii) how do local weather conditions impinge on migration behaviour. From an economic point of view, these are crucial questions which must be answered and therefore merit further research.

Diapause: The third key feature in the life-cycle of H. armigera is the ability to enter into a facultative pupal diapause (Diapause refers to the ability of Heliothis to extend its period of "hibernation" as a pupa in response to hostile environments, especially low outside temperatures). A facultative diapause ensures that widespread species are able to respond to differing environmental conditions for reproduction and survival. Diapause is induced in late instar larvae and pre pupal development through shortened days and temperatures falling below 20* C. Emergence from diapause occurs over a period of 3-6 weeks. This extended period ensures that at least some part of the overwintering population will encounter conditions favourable for development and reproduction.

In north India, since winter temperatures are often below 18* C, armigera goes into diapause in winter. However, in the south of India, winter temperatures rarely fall below 18* C. Hence there is no diapause and H. armigera breeds continuously. This factor makes the problem of control much more difficult since continuous breeding is more likely to result in overlapping generations of the pest, each at different levels of susceptibility to pesticides.

Fecundity: The high fecundity of armigera combined with a short life span gives it a capacity for rapid population increases. Between 1000-1500 eggs per female are typical over the reproductive life span of 8-10 days. It is well documented that fecundity is influenced by temperature, humidity and larval and adult nutrition. Prolonged exposure to temperatures above 35*C reduces adult survival fertility and fecundity.

The number of generations possible each year is directly influenced by temperature, host sequence and host suitability. Seasonal populations are also influenced by these factors. Rainfall indirectly influences seasonal abundance by affecting the abundance and suitability of host plants. Where hosts are continually available (as in south India), armigera may breed continuously, completing a generation in as little as 28-30 days and passing 10-11 generations in a year. This has the important implication that resistant strains, due to selection pressure, can build up extremely rapidly.

## Heliothis Population Dynamics: Modelling and Prediction

We will now discuss the various factors that have an important impact on the Heliothis population in a particular area. In terms of our algebraeic model, we need to identify the significant variables in the carrying capacity function for H. armigera. We thus need to look at the role of weather variables (temperature and rain), role of an overwintering population, availability of host plants-sequence and suitability, role of predators, influence of cropping patterns-monoculture versus multicropping, continuous cropping versus period of fallow, role of source crops, migration and uncultivated hosts.

In general most of the factors mentioned above are poorly researched and there is little if any evidence of the effect of these factors on armigera populations. Some entomologists claim that a hot dry spell is conducive to rapid pest multiplication partly by reducing the length of the pest cycle and partly by increasing the nutritional quality and susceptibility of many wild and cultivated host plants (Pimbert & Srivastava, 1991). Others claim that high rainfall influences the pest population positively by increasing host plant abundance (Fitt,1989). Evidence from ICRISAT (Pimbert & Srivastava, 1991) shows that rainfall deficit and high abundance of armigera are positively correlated. Thus it seems that, in the net, a long dry spell is conducive to armigera growth. It was also shown in the Pimbert & Srivastava study that long range migration had only a limited role in the population dynamics during the period of analysis.

Cropping patterns can have a profound influence on the abundance of armigera. The spread of continuous cropping is often quoted as being an important reason for the emergence of armigera as a major pest. Some researchers claim that monoculture exacerbates the pest problem whereas others support the opposite notion. It has been found that intercropping cotton with pigeon pea (both susceptible crops) reduces the pest damage on both (Nigel Armes, pers. com.) but the reasons are not clear. Source crops can exert an important influence on the resistance of these pests. For example, the large unsprayed sorghum areas in southern Maharashtra provide a source of susceptible moths which lead to a dilution of resistance in Andhra Pradesh, through migration (Armes, et al., 1991).

Because of the gap in research knowledge, armigera population models have been understandably limited. For example, of the few that exist (El-Zik and Frisbie, 1990), the MOTHZV program is used to predict the seasonal dynamics of H. zea and H. virescens in Texas. These predictions require as inputs the size and timing of early season light trap catches. Similarly, pheromone trap catches are thought to be good predictors for the size of the early pest broods in the Lam farm area of Guntur (Dr. Venugopal Rao, pers. com., Metcalf and Luckmann, 1982) and indicate the timing of pesticide application. However, since population dynamics of the Heliothis group of species are less predictable elsewhere, these examples are too few to be generalized and therefore of limited value. One major limitation of the present modelling exercises is that they are typically within season models and do not look at the between season dynamics. Clearly, it is extremely important to develop models that will give longer term population predictions, so that appropriate pest control policies can be instituted well in time. Nevertheless, the present models can act as the basis for more detailed analysis of general applicability.

What is the bottom line emerging from the foregoing discussion? In general, given our present state of knowledge it is believed that the regional abundance of H. armigera may be determined mainly by abiotic (e.g. climatic) rather than by biotic factors. However, much more research is required before we can confidently identify the important factors determining armigera populations in India. Put in terms of our algebraic model we conclude that at the present stage of research we are not in a position to determine a stable carrying capacity relationship for H. armigera--an equation that will have a useful predictive value for pest control purposes. To reiterate, research in this area is likely to yield high returns.

## The Heliothis Cycle in the Guntur Area

Due to the development of irrigation facilities, Guntur and the other coastal cotton growing areas are now in continuous cropping farming systems with the earlier summer fallow period being given over to summer vegetables such as okra, eggplant and tomato. The cultivation of summer crops ensure a continuous supply of hosts for Heliothis which (in the absence of diapause) can breed through the year. The pattern of propagation of the pest is as follows:

1) March to July: Low initial population in summer vegetables such as okra, eggplant, tomato and uncultivated hosts.

2) mid-July to mid-November: Cotton is sown in about mid-July and is in the full vegetative stage by the end of August. By the end of September it is in the boll setting stage and highly attractive to H. armigera. Thus the pest migrates to cotton and multiplies on that crop till early November.

3) November-December: By November, cotton loses its vigour and is no longer attractive to the Heliothis. It therefore migrates to red gram and pigeon pea which are in full blooming stage by early November. The pest feeds on red gram till about the end of December.

4) December-February: By the end of December, when red gram loses its attraction, chickpea has come into full bloom and the Heliothis stays on it till February, when the cycle is repeated.

The description of the pest cycle is consistent with the assertion that Heliothis has the ability to infest and damage several crops within a growing season. Clearly, this fact will be important when we estimate the losses due to the pest.

## V. INSECTICIDE RESISTANCE OF HELICOVERPA (H. ARMIGERA)

The susceptibility (or the lack of it) of an insect pest to a particular pesticide is measured by an index termed the Resistance Factor[3] (RF) for the pest. The RF is calculated as the ratio of the

[3] An alternative (and arguably better) measure is the discriminating dose (DD) test. This test also gives us an idea about the distribution of resistance in a certain field population of pests. Unfortunately, DD values were unavailable on an extensive basis for this area and so we are forced to considering the RF

pesticide concentration required to kill 50% of the sample of field larvae, to the concentration required to kill 50% of the sample of the susceptible laboratory strain (for details, see Armes et al.,1990). (The laboratory strain is chosen such that it has not been subjected to selection pressure on account of pesticide exposure i.e. it has to be a truly susceptible strain.) Thus, the higher is the value of the RF index, the more resistant is the pest and conversely, the less effective is the pesticide in question.

The ability of the farmer to keep pest populations below economically damaging levels through the use of pesticides is called successful field control. The determination of the success of field control, requires knowledge of a number of entomological and agronomic factors (Forrester, 1990). In addition to resistance levels, we also need information on pest pressures, presence of susceptible sibling species, application conditions, genetics of resistance, the relationship betweeen field dose and functional dominance, etc. Since the information on these factors often does not become available until much later, after several years of research, it is difficult to predict the extent of field control expected in any one season. On the other hand, it is easier to identify the conditions under which field failure is likely to occur. Field failure refers to the situation when a farmer is unable to control the pest to below the economic threshold, through the application of available pesticides. Clearly, the experience of the cotton farmers in 1987/88 is best described as a situation of

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values.

field failure. Based on dif..rent cases of field failure reported worldwide, two necessary conditions have been identified. The first is that the resistance of the pest to commonly used pesticides should be quite high. In terms of the RF index, the value should be at least fifteen for cypermethrin, one of the widely used pyrethroids in the area (Nigel Armes, pers. com.). The second necessary condition is that there should be a strong pest pressure i.e. a high level of pest infestation on the crop. It is much more difficult to quantify this variable since it depends upon the type of cotton grown, the cropping mix, etc., however, taken together, it is believed that these two conditions are sufficient to cause field failure.

We now move on to a discussion of the important factors determining Heliothis resistance and how resistance has evolved (in terms of changes in the RF values) over the years, particularly with reference to the Guntur area.

## The Dynamics of Heliothis Resistance to Pyrethroids in Coastal Andhra Pradesh

Armes et al.(Armes et al., 1991) have succintly summarised the factors that drive the pattern of development of resistance in Andhra Pradesh. They say:

"The geographic and temporal variations in the severity of pyrethroid resistance in H. armigera in the Andhra Pradesh region arises because of dynamic interactions between local selection pressures and the immigration of resistant and susceptible moths at certain times of the year." (underlined phrases, ours)

Keeping in mind the above observation, we will elaborate on the role of local selection pressures and the role of pest migration as well as the existence of "dilutants" on the level of resistance. We will also discuss the development of resistance to synthetic pyrethroids (SPs) in other regions of India and finally, we will briefly look at the development of resistance to the other commonly used pesticides on cotton.

## Local Selection Pressures

SPs entered the Indian market in the late 70s and assumed importance in the early 80s. The Guntur market has always been a big consumer, accounting for as much as 40% of the total SPs consumed in India. They are cheap (SPs cost only about a third of the price of the traditional pesticides, per application), and broad spectrum and they initially gave unprecedented levels of pest control. This led to two developments. First, farmers began to place excessive reliance on their use. Instead of need based spraying farmers reverted to time based spraying. This led to an excessive use of these pesticides. Second, side-by-side with the first development, because SPs quickly destroy the most susceptible population, they put a strong selection pressure on the surviving population so that resistant strains can develop rapidly. Thus bioassay evidence (Mehrotra, 1991) indicates that if the survivors of a first pyrethroid spray are inbred in the laboratory the RF can jump to as high as 28 fold in two generations. On the other hand, populations of Heliothis collected from the fields subjected to two SP sprays (one of deltamethrin and one of fenvalerate) in a single insect generation, showed a RF of 5.2. On the basis of these findings it is concluded that Heliothis should not be subject to more than two pyrethroid treatment in a single generation. This finding has to be contrasted with the fact that farmers in this area have been applying several rounds of SPs in succession. Clearly, given the technical "optimum", farmers are overusing SPs and it is to be expected that resistant strains will develop rapidly. An important policy implication of this finding is that alternating the use of SPs with the traditional pesticides is crucial to the management of Heliothis resistance (also see Forrester, 1990).

In addition, often poor coverage due to faulty equipment, bad timing and sublethal doses by farmers, all of which are observed to be occurring in the Guntur area, exacerbate the problem of the survival of pests after spraying.

The cumulative impact of these local selection pressures was reflected in changes in the RF values for cypermethrin and fenvalerate which rose from 0.6 and 0.8 in July 1986 to 40 and 120 in November 1987. By March 1988, they were as high as 750 and 287 respectively. These values were recorded at ICRISAT. Data from Juzzuru, a town close to Guntur recorded a value of 325 in October 1987, a value which vastly exceeded the requirement for field failure. In overall terms, resistance to SPs was not a feature of Heliothis till 1986 and has obviously developed since then.

Role of Migration and Existence of Susceptible Refugia

Table 1 reports the RFs of Heliothis to cypermethrin at various locations since 1987. The numbers reported therein help us in tracing the dynamics of resistance as it has evolved over time and across some parts of Andhra Pradesh. Several characteristics of the development of resistance may be noted.

TABLE 1: DEVELOPMENT OF H. ARMIGERA RESISTANCE TO PYRETHROIDS

| DATE | LOCATION | CROP | RF READING/DELHI |
|---|---|---|---|
| 20th JULY '86 | ICRISAT | CHICKPEA | 0.6/ |
| 23rd OCT. '87 | JUZZURU | COTTON | 325/25 |
| 4th NOV. '87 | ICRISAT | PIGEONPEA | 40/3 |
| 17th NOV. '87 | ICRISAT | PIGEONPEA | 125/16 |
| 30th NOV. '87 | ICRISAT | CHICKPEA | 85/6 |
| 17th MARCH '88 | ICRISAT | PIGEONPEA | 750/50 |
| 17th SEPT. '88 | AUREPALLE (100 Kms. south of Hyderabad) | PIGEONPEA | 0.8/ |
| 16th SEPT. '88 | ICRISAT | PIGEONPEA | 1.8/ |
| NOV. '88 | PRAKASAM | COTTON | 60/4 |
| NOV. '88 | JUZZURU | COTTON | 30/2 |
| DEC. '88 | ICRISAT | PIGEONPEA | 1.5/ |
| DEC. '88 | SHANKARPALLE (near ICRISAT) | TOMATO | 5.2/ |
| 2nd OCT. '89 | ICRISAT | PIGEONPEA | 79/4 |
| 20th NOV. '89 | ICRISAT | PIGEONPEA | 929/44 |
| 18th NOV. '89 | ICRISAT | CHICKPEA | 214/10 |
| 24th NOV. '89 | GUNTUR | COTTON | 2100/100 |
| 24th NOV. '89 | CICR | COTTON | 460/35 |
| 15th MARCH '90 | ICRISAT | PIGEONPEA | 214/16 |
| 20th NOV. '90 | ICRISAT | PIGEONPEA | 41/3 |
| 22nd NOV. '90 | ICRISAT | CHICKPEA | 54/4 |
| 12th DEC. '90 | ICRISAT | COTTON | 83/6 |
| 28th NOV. '90 | GUNTUR | PIGEONPEA | 80/6 |
| 13th MARCH '91 | ICRISAT | PIGEONPEA | 332/26 |
| 23rd JAN. '91 | TADIKONDA (GUNTUR) | COTTON | 250/9 |
| 24th JAN. '91 | KUMARIPALEM(GUNTUR) | PIGEONPEA | 830/64 |
| 20th MARCH '91 | SHANKARPALLI | CHICKPEA | 58/4 |
| 19th APRIL ,91 | NARSAPUR (ICRISAT) | TOMATO | 20/2 |

Source: Armes et al. (1991) and the author's own calculations.

(a) First, there has been a very rapid development of resistance--within the space of a few years. Furthermore, the development of resistance exhibits a threshold effect in the sense that upto July 1986 there is no evidence of resistance whereas by October 1987, the RF had taken on a value of 325/25 at Juzzuru and 40/3 at ICRISAT. It may also be noted that the RF values recorded with respect to cypermethrin (and fenvalerate) are the highest yet recorded from field populations of H. armigera anywhere in the world. In Australia, field failures were recorded in areas where H. armigera showed a tolerance of upto 15 fold to cypermethrin. H. armigera from cotton areas in Thailand showed a RF of 102 to cis-cypermethrin and 82 fold to trans-cypermethrin and in these areas the cotton crop was severely destroyed. The overall conclusion is that the RF values found for the coastal AP in 1987/88 and 1989/90 are entirely consistent with an inability to control the cotton insects with SPs.

(b) Pyrethroid resistance at ICRISAT and in the Guntur cotton belt has varied substantially between the years. By 1988, larvae collected from rainy season crops were once again susceptible and resistance in the Guntur cotton belt during the post rainy season had dropped to between 30/2.2 and 60/4.3. At and around ICRISAT, the larvae were fully susceptible in the post rainy season of 1988.

In the post rainy season of 1989, the RF was as high as 929/44 at ICRISAT. In Guntur, for a field strain collected from cotton, it was as high as 2100/100, the highest ever recorded. Although the resistance levels in the 1989/90 season were much higher than in

1987/88, at the field level they went largely unnoticed because the pest pressure was low and despite poor control, damage remained below tolerance limits.

The resistance levels were at a more moderate level in the 1990/91 season. For example the RF was 41/3 on pigeonpea at ICRISAT and 80/6 on cotton. In fact the highest level recorded there was 830/60 on pigeonpea in January 1991.

(c) The changes in resistance are clearly influenced by the seasonal migration patterns as exhibited by a high degree of correlation between the two. Thus, two sorts of changes in resistance are observed both of which are entirely consistent with the migration patterns described in an earlier chapter. First, the post rainy season dilution of resistance is probably due to the fact of influx of predominantly susceptible moths emerging from

TABLE 2
Cypermethrin RFs wrt the Reading strain recorded during November.

| YEAR | ICRISAT | GUNTUR |
|---|---|---|
| 1987 | 125 | 325 |
| 1988 | 2 | 30 |
| 1989 | 214 | 2100 |
| 1990 | 41 | 80 |

Source: Presentation by N.J. Armes, ICAR/USDA/IOPRM Joint Meeting, Hyderabad October 1991.

large areas of unsprayed sorghum in Maharashtra. Second, the rise in resistance from November to February, observed around ICRISAT mirrors the development of resistance in Guntur. This arises as a result of the migration of resistant moths inland from coastal AP, aided by the November winds. The data in Table 2 above, further supports this assertion.

In overall terms, there is clear evidence to indicate that there is considerable gene flow between H. armigera populations from different regions of the country.

## The Spread of SP Resistance to other Regions of India

Available evidence seems to indicate that resistance to SPs is probably quite widespread in the south of India--AP, Karnataka and Tamil Nadu (Armes et al., 1991). This is not too surprising in view of the evidence presented on migration and the resulting intermixing of strains. However it is also disturbing to note that resistance seems to be quite widespread in North India and is increasing at a rapid rate (Mehrotra, 1991). The RF at Delhi in April 1991 and at Karnal in May of the same year was 26/2. Hissar, which is an important cotton growing tract and where there is a significant use of SPs showed an RF of 280/22. Thus, it seems to be the case that local selection pressures are leading to the development of increasing resistance in north India. In fact the 1990/91 cotton season in Punjab/Haryana was marked by extensive field failures, and it is estimated that about 30% of the crop was lost to Heliothis.

From a macro perspective the major implications of the widespread development of Heliothis resistance to SPs, is the fact that the refugia (refugia are defined to be cultivated areas which are largely unexposed to pesticide sprays and thus harbour a stock of susceptibles) of susceptible Heliothis populations are fast dwindling. This is partly due to the contamination of susceptible pests with the resistant strains, partly due to increasing (and often faulty) use of SPs leading to local selection pressures and partly due to changing cropping patterns in some areas of the country. A good example of the last is the substitution of land under unsprayed sorghum, in Maharashtra, by oilseeds, brought about by the recent increase in the procurement price for oilseeds vis-a-vis sorghum. This has clearly shrunk the source of susceptible pests and therefore reduced the potentially diluting effect on Heliothis resistance in south India.

Resistance to other Pesticides

Resistance to DDT at ICRISAT was as high as 70/5 even by July 1986. It jumped to 303/22 by November 1987 and has stayed at about that level since. There is some evidence to indicate that resistance to SPs enhances cross-resistance to DDT (McCaffery et al., 1989).

As regards endosulfan, the Juzzuru strain already shows a moderate 13 fold level of tolerance. In Australia poor control resulted in the case where field populations showed a resistance factor greater than 21 fold. Note however that in India control difficulties were experienced at ICRISAT, when the the tolerance level was only 7 fold (Mc Caffery et al., 1989). Since endosulfan is a critical alternative compound in a pyrethroid management strategy, resistance to endosulfan could create serious problems in controlling armigera in future.

Finally, there is no evidence of resistance to monocrotophos, quinalphos (although tolerance to quinalphos had increased to 5-9 fold in the 1990/91 season, as compared to 2-4 fold in the 1989/90 season) and methomyl in any of the field strains examined so far. Thus, reported difficulties with these pesticides may reflect inadequacies of the techniques used in the application of pesticides in general.

## Summary

The evidence available from the resistance monitoring studies points to the fact that resistance of Heliothis to SPs is increasing in all parts of the country--partly due to increased local selection pressures (due to increased use of this group of pesticides) and partly due to the reduction of susceptible refugia (arising from policy induced changes in relative agricultural prices). <u>There are two important economic implications flowing out of this</u>. The first implication of increasing resistance (almost all over India, attributable to the overuse of pesticides) is to increase the <u>continuing losses</u> due to increased Heliothis damage. The second major implication is that RF values in some parts of the country are at levels that are entirely consistent with field failures,i.e., it seems likely that <u>indiscriminate pesticide use has increased substantially the probability of catastrophic crop devastation</u> of the sort that occurred in 1987/88. That field failure has, in fact, not occurred is because pest populations have been low due to mostly fortuitous (and non policy influenced) factors. If another cotton crop disaster is to be averted, it is vital that country wide resistance management strategies be immediately implemented.

In the next few sections, we will try to quantify both of the costs mentioned above--the extent of increase in continuing crop losses, as well as the expected value of crop losses in the event of a complete crop failure, due to the increased resistance of Heliothis to pyrethroids.

## VI. ESTIMATING THE DAMAGE DUE TO HELIOTHIS IN GUNTUR

In this section we will estimate the losses resulting from "total" cotton crop failures in Guntur. Before we go on to the estimation a brief history of cotton growing in Guntur is necessary, especially for purposes of identifying the years of crop devastation.

The Guntur area has had a long history of cotton cultivation. Indeed the soils in that area are referred to as "black cotton soils", although chillies, tobacco and rice are important crops too. With the introduction and widespread adoption of hybrid cotton varieties since about the late seventies, cotton production in the district shot up from 117 thousand bales in 1979/80 to 324 thousand bales in 1982/83. Refer to Table 3. In fact, the production of 567 thousand bales in 1983/84 was an all time high, being exceeded only

TABLE 3: AREA, PRODUCTION AND YIELD OF COTTON LINT IN GUNTUR

| YEARS | AREA (HA.) | PROD. (BALES) | YIELD (KGS/HA) | GROWTH RATES AREA (HA.) | GROWTH RATES PROD. (BALES) | GROWTH RATES YIELD (KGS/HA) |
|---|---|---|---|---|---|---|
| 1970/71 | 9474 | 6211 | 111.4 | | | |
| 1971/72 | 22981 | 34088 | 252.2 | 142.6 | 448.8 | 126.3 |
| 1972/73 | 26040 | 24738 | 161.5 | 13.3 | -27.4 | -36.0 |
| 1973/74 | 54791 | 126019 | 391.0 | 110.4 | 409.4 | 142.1 |
| 1974/75 | 75571 | 178851 | 402.3 | 37.9 | 41.9 | 2.9 |
| 1975/76 | 50995 | 103790 | 346.0 | -32.5 | -42.0 | -14.0 |
| 1976/77 | 78864 | 119688 | 258.0 | 54.7 | 15.3 | -25.4 |
| 1977/78 | 86204 | 50201 | 99.0 | 9.3 | -58.1 | -61.6 |
| 1978/79 | 55303 | 117114 | 360.0 | -35.8 | 133.3 | 263.6 |
| 1979/80 | 66934 | 161823 | 411.0 | 21.0 | 38.2 | 14.2 |
| 1980/81 | 89691 | 246386 | 467.0 | 34.0 | 52.3 | 13.6 |
| 1981/82 | 116479 | 302160 | 441.0 | 29.9 | 22.6 | -5.6 |
| 1982/83 | 120816 | 324071 | 456.0 | 3.7 | 7.3 | 3.4 |
| 1983/84 | 140768 | 567212 | 685.0 | 16.5 | 75.0 | 50.2 |
| 1984/85 | 172272 | 495535 | 489.0 | 22.4 | -12.6 | -28.6 |
| 1985/86 | 187297 | 294166 | 267.0 | 8.7 | -40.6 | -45.4 |
| 1986/87 | 131000 | 350000 | 454.2 | -30.1 | 19.0 | 70.1 |
| 1987/88 | 183000 | 224000 | 208.1 | 39.7 | -36.0 | -54.2 |
| 1988/89 | 173000 | 260000 | 255.5 | -5.5 | 16.1 | 22.8 |
| 1989/90 | 158000 | 383000 | 412.1 | -8.7 | 47.3 | 61.3 |
| 1990/91 | 158000 | 600000 | 645.6 | 0.0 | 56.7 | 56.7 |
| 1991/92 | 168148 | 585000 | 591.4 | 6.4 | -2.5 | -8.4 |

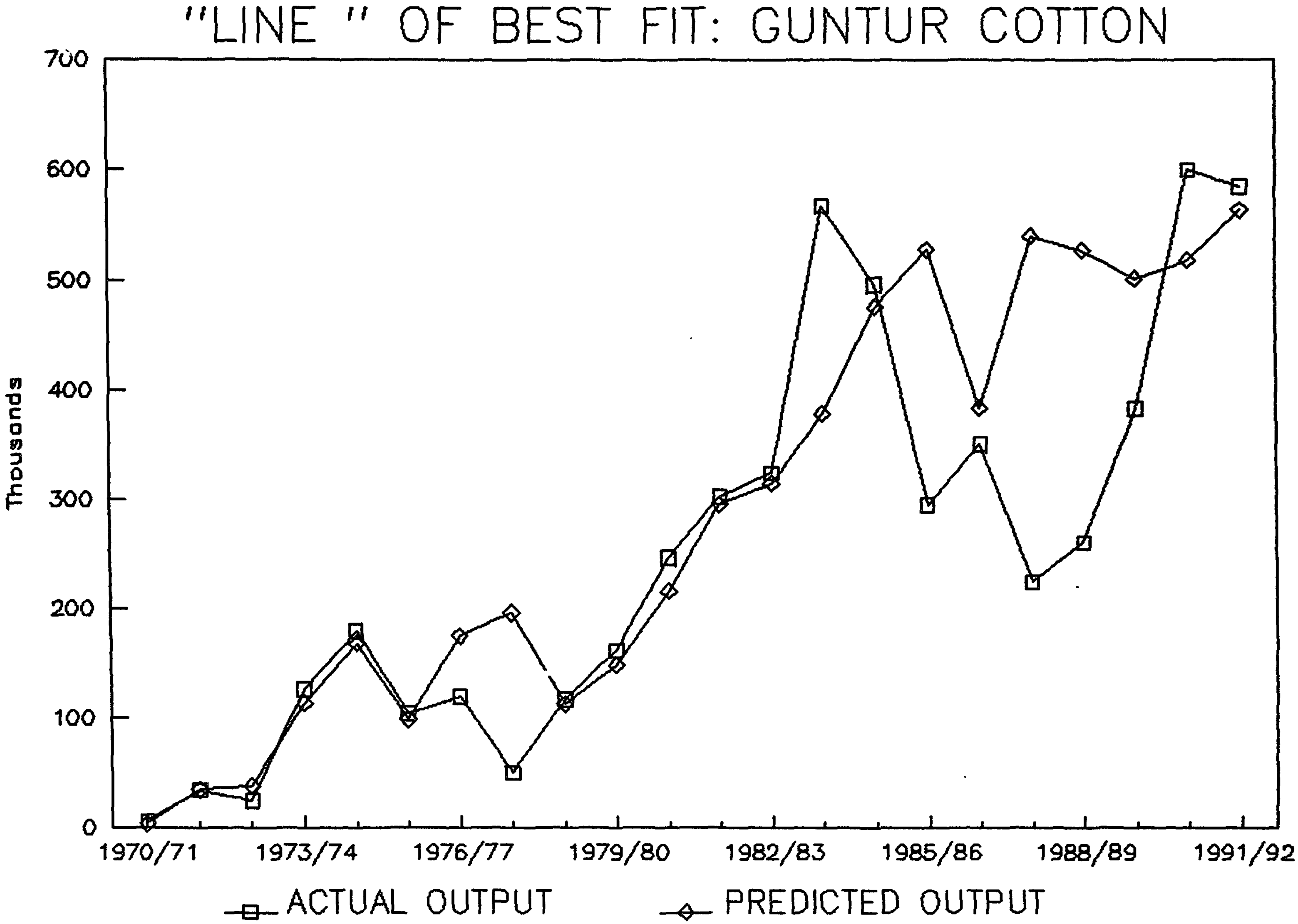
Source: District Agricultural Authority, Guntur.

in the 1990/91 season and is expected to be exceeded in the 1991/92 season. Recent estimates put the agricultural income generated by cotton at between 25% and 30% of the total income originating from agriculture, for the district. In addition to the quarter of a million cotton farmers in the district the basic cultivation activities provide employment to about half a million farm labourers. Downstream processing activities such as ginning, baling, oil pressing and handloom weaving provide employment to hundreds of thousands more workers, in the 258 ginning and 34 pressing mills in the district. In sum, the production and processing of cotton is an extremely crucial part of the total economy of the district and forms the lifeline of a large number of people.

Clearly, fluctuations in cotton production can make for huge uncertainties in the livelihoods of these people in this area. Unfortunately, with the growth in cotton output we have also seen several episodes of widespread crop failure due to the farmers'inability to control various cotton pests, especially in recent years. Thus, there was considerable damage due to white fly in the 1985/86 agricultural season. With the development and spread of whitefly resistant varieties (LK-861 and LPS-141), this pest seems to have been thwarted. However, in the 1987/88 season, H. armigera assumed the status of a major pest and almost totally devastated the crop in several parts of the district leading to the bankruptcy of at least several hundreds of farmers. Heliothis losses were again quite significant in the next cotton growing season but since then the problem appears to be under control, although as we will see subsequently, cotton cultivation in this area seems to be balanced on a knife edge and much needs to be done before sustainability in cotton production can be achieved.

Losses due to Pest attacks

Table 3 has the data on cotton production (in bales of lint, each bale weighing 170 Kgs) and the acreage for the years 1970/71 to 1991/92. (Output for 1991/92 is an estimate, as the cotton season is not yet over). Of the 22 observations available to us, five are identified as outliers and eliminated from the estimation of a trend line. These are: 1977/78, in which season a severe cyclone damaged a large proportion of the standing crop, 1983/84, when the output was abnormally high in Guntur and also all over India because of very favourable weather conditions, 1985/86, whitefly damage year, and 1987/88 and 1988/89, both years when Heliothis damage was very significant. The remaining ("normal") years were used for curve fitting. Two approaches were tried, the first by using output as the dependent variable and a second in which yield of cotton lint per hectare was used as the dependent variable. Several different variables, including the use of time and $(\text{time})^2$ as the independent variables, and several different functional forms (semilog, sigmoid, quadratic, etc.) were tried. Appendix 1, has a brief discussion on the reliability and validity of the approach, but the best fitting form was obtained by using total output (Q) as the dependent variable and the acreage (A),


"LINE " OF BEST FIT: GUNTUR COTTON
Thousands
0
100
200
300
400
500
600
700
1970/71
1973/74
1976/77
1979/80
1982/83
1985/86
1988/89
1991/92
ACTUAL OUTPUT
PREDICTED OUTPUT

time and $(\text{time})^2$ as the independent variables. Thus the estimated equation is:

$$Q = -14532.1 + 2.77A - 8437.57t + 617.33t^2 \qquad (26)$$

$$R^2 = 0.94$$

Now, the difference between the predicted value as given by the trend line and the actual output gives an estimate of the potential loss in output for that year. Table 4 gives the details on pest damages for the eighties. The damage due to cyclone in 1977/78 is given for comparison purposes. For 1987/88, the aggregate district wide damage to cotton was almost 59% of the potential cotton output for the year. Thus the loss of cotton lint was valued at about Rs. 163 crores ($126 m). Additionally, the potential loss of cottonseed oil is estimated to be in the region of Rs. 44 crores ($34 m). It may also be kept in mind that within this aggregate picture, many hundreds of farmers suffered a 100% loss of their crop. Since a large porportion of them were small and marginal farmers, working on rainfed land and able to cultivate only one crop in the year, the failure of the crop plunged them into financial ruin and/or into irredeemable indebtedness. The fact of several farmers' suicides in that year is evidence of the widespread nature of this problem.

In 1988/89, although it did not get as much publicity as the previous season, Heliothis damage was almost as severe and over 50%

TABLE 4: ECONOMIC LOSSES FROM PEST ATTACKS IN COTTON IN GUNTUR.

| | ---BALES--- | | | | | | (RS. CRS.) | | LOSS AS | REASON |
|---|---|---|---|---|---|---|---|---|---|---|
| YEARS | ACTUAL PROD. | PREDICTED PROD. | PROD. LOSS | LINT PRICE | LINT LOSS | SEED PRICE | SEED LOSS | TOTAL LOSS | % OF POT-ENTIAL | FOR DAMAGE |
| 1970/71 | 6211 | 3877 | | | | | | | | |
| 1971/72 | 34088 | 34686 | | | | | | | | |
| 1972/73 | 24738 | 37804 | | | | | | | | |
| 1973/74 | 126019 | 113286 | | | | | | | | |
| 1974/75 | 178851 | 167934 | | | | | | | | |
| 1975/76 | 103790 | 98248 | | | | | | | | |
| 1976/77 | 119688 | 174992 | | | | | | | | |
| 1977/78 | 50201 | 196135 | 145934 | 1531 | 38.0 | 156.3 | 7.8 | 45.7 | 74.4 | CYCLONE |
| 1978/79 | 117114 | 112641 | | | | | | | | DAMAGE |
| 1979/80 | 161823 | 148134 | | | | | | | | |
| 1980/81 | 246386 | 215664 | | | | | | | | |
| 1981/82 | 302160 | 295588 | | | | | | | | |
| 1982/83 | 324071 | 314591 | | | | | | | | |
| 1983/84 | 567212 | 378059 | | | | | | | | |
| 1984/85 | 495535 | 474744 | | | | | | | | |
| 1985/86 | 294166 | 527040 | 232874 | 1460 | 57.8 | 314.8 | 24.9 | 82.7 | 44.2 | WHITEFLY |
| 1986/87 | 350000 | 383114 | 33114 | 1884 | 10.6 | 314.4 | 3.5 | 14.1 | 8.6 | ATTACK |
| 1987/88 | 224000 | 540247 | 316247 | 3035 | 163.2 | 411.3 | 44.2 | 207.4 | 58.5 | HELIOTHIS |
| 1988/89 | 260000 | 526965 | 266965 | 2953 | 134.0 | 430.0 | 39.0 | 173.1 | 50.7 | ATTACK |
| 1989/90 | 383000 | 501075 | | | | | | | | |
| 1990/91 | 600000 | 517948 | | | | | | | | |
| 1991/92 | 585000 | 564150 | | | | | | | | |

NOTES:
1) The best fit trend line gives the potential output for abnormal years.
2) Cotton lint and cottonseed prices from Gulati, Kishor and Pursell study.
3) Production figures for cotton from official AP agricultural publications.

of the crop was ravaged by the pest, with total lint and cottonseed oil losses amounting to Rs. 173 crores ($120 m).

The damages due to whitefly attack in 1985/86 amounted to about Rs. 83 crores ($68 m) and formed about 44% of the potential output. In the following season, whitefly damages comprised only about 9% of the potential output. Thus, by contrast, Heliothis damages have been much more severe. This vindicates our earlier general claim that Heliothis is the current number one pest in cotton, capable of causing substantial and continuing losses. Clearly, this emphasizes the need to take immediate steps to control this pest in order to sustain the cotton economy.

## VII. ESTIMATING THE EXTERNALITY COSTS OUTSIDE GUNTUR COTTON

In this section, we will attempt to estimate external costs arising from Heliothis damage. Broadly speaking, there are two types of costs. First, there is the damage to other crops (other than cotton) in the Guntur area, contiguous to the cotton growing tracts. Second, there are the damages on cotton and other crops occurring in the more distant inland areas, due to the capability of the pest for long distance migration.

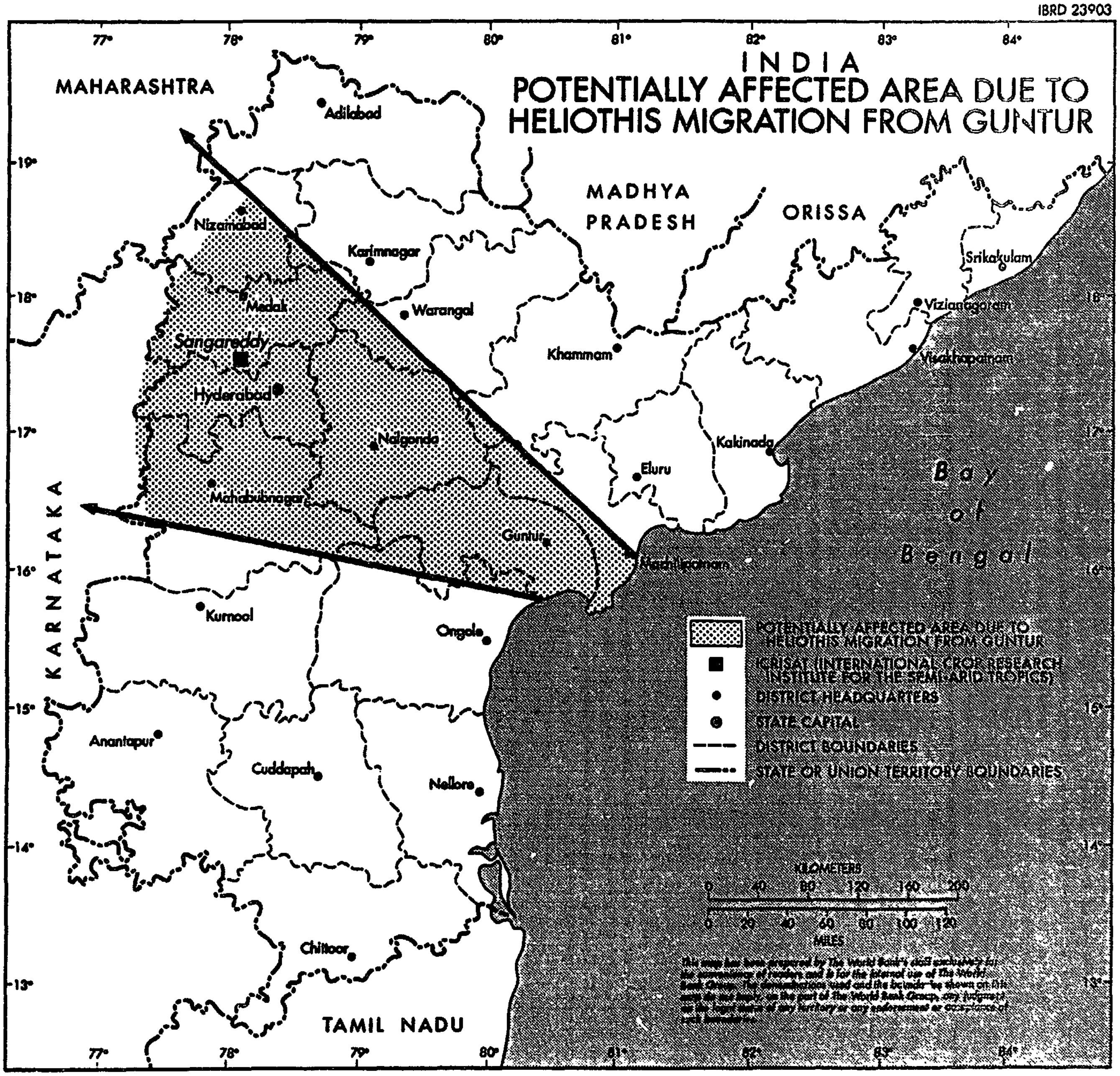
On the basis of our earlier discussions regarding the ecology of Heliothis in India, we had reached the following important conclusions:

a) H armigera is a highly polyphagous pest, attacking not only cotton but a variety of other crops such as pigeon pea, chick pea, sunflower, sorghum, maize, mung bean, soyabeans, tobacco, chillies, capsicum, okra, tomatoes, cabbages and cauliflowers. Since these are all crops grown in the local area and within the migratory potential of the pest, it is capable of causing continuing losses in agriculture.

b) Guntur (and Krishna and Prakasam also) forms a local "hot spot" of resistant pests. This has arisen largely due to the indiscriminate use of huge amounts of pesticides on cotton in the area. Resistance monitoring studies have shown that Heliothis populations in Guntur have RFs close to or exceeding the values consistent with field failure levels.

c) There is widespread migration of the moths into the inland areas of the state, especially in November, when the they are assisted by the prevailing wind patterns. In other words, the relatively more resistant Guntur strains are "contaminating" the other areas and raising the RFs in those areas towards the field failure levels. The fact that there have been only sporadic incidents of field failure reported in other areas (despite a continuing selection pressure) is because population pressures have not been high enough to precipitate a crisis situation. Nonetheless, it must be stated (Pedgley et al., 1987) that if resistant moths continue to migrate from Guntur, it is very likely that populations will build up to field failure levels in a short period of time.

MAP 2


IBRD 23903
INDIA
POTENTIALLY AFFECTED AREA DUE TO HELIOTHIS MIGRATION FROM GUNTUR
MAHARASHTRA
MADHYA PRADESH
ORISSA
KARNATAKA
TAMIL NADU
Bay of Bengal
Adilabad
Nizamabad
Karimnagar
Medak
Sangareddy
Warangal
Hyderabad
Khammam
Nalgonda
Mahabubnagar
Guntur
Machilipatnam
Eluru
Kakinada
Srikakulam
Vizianagaram
Visakhapatnam
Kurnool
Ongole
Anantapur
Cuddapah
Nellore
Chittoor
POTENTIALLY AFFECTED AREA DUE TO HELIOTHIS MIGRATION FROM GUNTUR
ICRISAT (INTERNATIONAL CROP RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS)
DISTRICT HEADQUARTERS
STATE CAPITAL
DISTRICT BOUNDARIES
STATE OR UNION TERRITORY BOUNDARIES
KILOMETERS
0 40 80 120 160 200
0 20 40 60 80 100 120
MILES
77° 78° 79° 80° 81° 82° 83° 84°
19° 18° 17° 16° 15° 14° 13°

By considering the feasible distance for migration and the "back-tracks"[4], it is estimated that resistant Heliothis from Guntur can affect crops in the districts of Nalgonda, Mahbubnagar, Rangareddy and Medak/Sangareddy (refer to Map 2). Note that detailed resistance monitoring and migration studies are required to get a more reliable idea of the potentially affected areas.

Table 5, reports the output and value of crops grown in these districts as well as in Guntur which are vulnerable to Heliothis attack. The total value of the vulnerable crops (including cotton) outside Guntur was Rs.350 crores (about $210 m), in 1989/90. In Guntur the total value of susceptible crops (excluding cotton) was about Rs.320 ($192 m) crores. The total amount of Rs.670 crores ($400 m), which potentially could have been affected was about two and a half times the value of cotton grown in Guntur.

## Continuing Crop Losses

As has been repeatedly stressed, in this section and elsewhere, we need to estimate the continuing losses due to an increase in the general level of resistance as well as the (expected) catastrophic losses due to an increase in the probability of field failure.

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[4] As stated earlier, back tracks indicate the migration path for Heliothis moths, based on moth catches at ICRISAT and on the prevailing wind patterns. Pedgley et al. (Pedgley et al., 1987) find that their back tracks come mostly from the Andhra Pradesh coast, East or South-East of ICRISAT. Map 2 gives an idea of the districts that can be potentially affected by moths migrating from Guntur.

TABLE 5: SIMULATING THE EXTERNAL DAMAGES DUE TO HELIOTHIS RESISTANCE IN 1989/90 (ON NON COTTON CROPS IN GUNTUR AND ALL CROPS IN OTHER AREAS)

| CROP | ---AFFECTED DISTRICTS--- MEDAK/ SANGAREDDY | RANGAREDDY | NALGONDA | MAHBUBNAGAR | 1985/86 TOT. OUTPUT (TONNES) | 1989/90 TOT. OUTPUT | 1989/90 AV.PRICE (RS./QTL.) | VALUE (RS. CRORES) | SIMULATIONS OF CONTINUING LOSSES 5% LOSS | 10% LOSS | 20% LOSS | ESTIMATION OF CATASTROPHIC LOSSES 50% LOSS ON PULSES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JOWAR | 91342 | 89781 | 46333 | 149769 | 377225 | 397697 | 160 | 66.81 | | | | |
| MAIZE | 57876 | 3752 | 1426 | 288 | 63342 | 65057 | 175 | 11.38 | | | | |
| CHICKPEA | 2627 | 2192 | 62 | 892 | 5773 | 5636 | 886.25 | 4.99 | | | | 2.5 |
| OTHER PULSES | 18364 | 29719 | 27708 | 19426 | 94217 | 101226 | 900 | 91.10 | | | | 45.6 |
| COTTON | | | | | | | | | | | | |
| a) LINT | 404 | 377 | 7184 | 9720 | 17685 | 18956 | 2938 | 9.47 | | | | |
| b) SEED | 808 | 754 | 14368 | 1944 | 17874 | 19158 | 450 | 1.47 | | | | |
| TOBACCO | 166 | 10 | 1328 | 4070 | 5574 | 5904 | 3770 | 22.26 | | | | |
| CHILLIES | 3662 | 6181 | 26390 | 2169 | 38402 | 46678 | 2200 | 102.69 | | | | |
| OKRA | 79 | 438 | 144 | 83 | 44640 | 60732 | 350 | 2.13 | | | | |
| CABBAGE | 1 | 99 | 1 | 0 | 9393 | 10572 | 100 | 0.11 | | | | |
| TOMATOES | 599 | 3841 | 225 | 2001 | 999900 | 1082324 | 350 | 37.88 | | | | |
| VALUE OF POTENTIALLY AFFECTED CROPS | | | | | | | | 350.29 | | | | |
| VALUE OF CONTINUING LOSSES | | | | | | | | | 17.5 | 35.0 | 70.1 | |
| **CROP** | **GUNTUR** | | | | **TOT OUTPUT** | **TOT OUTPUT** | **AV.PRICE (RS./QTL.)** | **VALUE (RS. CRORES)** | **5% LOSS** | **10% LOSS** | **20% LOSS** | **50% LOSS** |
| JOWAR | 6685 | | | | 6685 | 7048 | 168 | 1.18 | | | | |
| MAIZE | 1970 | | | | 1970 | 2023 | 175 | 0.35 | | | | |
| CHICKPEA | 1537 | | | | 1537 | 1500 | 886.25 | 1.33 | | | | 0.7 |
| OTHER PULSES | 83096 | | | | 83096 | 89277 | 900 | 80.35 | | | | 40.2 |
| TOBACCO | 4582 | | | | 4582 | 4854 | 3770 | 18.30 | | | | |
| CHILLIES | 77786 | | | | 77786 | 94549 | 2200 | 208.01 | | | | |
| OKRA | 332 | | | | 19920 | 27101 | 350 | 0.95 | | | | |
| CABBAGE | 127 | | | | 11811 | 13293 | 100 | 0.13 | | | | |
| TOMATOES | 1330 | | | | 199500 | 215945 | 350 | 7.56 | | | | |
| VALUE OF POTENTIALLY AFFECTED CROPS IN GUNTUR | | | | | | | | 318.2 | | | | |
| TOTAL VALUE (GUNTUR + OTHER AREAS) | | | | | | | | 668.5 | | | | |
| VALUE OF CONTINUING LOSSES IN GUNTUR | | | | | | | | | 15.9 | 31.8 | 63.6 | 88.9 |
| TOTAL (GUNTUR + OTHER AREAS) VALUE OF CONTINUING LOSSES | | | | | | | | | 33.4 | 66.8 | 133.7 | |
| % INCREASE IN THE COSTS OF CULTIVATION | | | | | | | | | 26.0 | 52.0 | 104.0 | |

NOTES: 1) The production figures for 1985/86 are drawn from the District Statistical Abstract, published by the Bureau of Economics and Statistics, Andhra Pradesh. Compound growth rates, as reported in, Acreage and Yield of Principal crops in India, have been used to get the 1989/90 outputs. For chillies and vegetable crops, growth rates have been derived from the statistics presented in the District Statistical Abstract.
2) For Okra, cabbages and tomatoes only the acreage has been reported. Yields have been drawn from the National Agricultural Research Project, AP: Krishna-Godavari Zone, Status Report, Volume 1.
3) All India average prices have been used, as drawn from the Agricultural Situation in India. Cotton prices have been taken from the Gulati, Kishor and Pursell report.

Strictly speaking (as highlighted by the theoretical model in Section III), to be able to estimate the losses due to a potential attack by resistant Heliothis, we need a (stable) relationship linking pest population, its RF and migratory potential in Guntur, to damage on noncotton crops in Guntur as well as all crops in the districts of Nalgonda, Mahbubnagar, Rangareddy and Medak/Sangareddy. Unfortunately, work in this area is in very preliminary stages (A.B.S King, pers com.) and it is extremely crucial to devote more resources to research in this field. Thus, on the basis of some indirect evidence[5] a sensitivity analysis has been performed, with the percentage of crop damage at 5%, 10% and 20%, respectively (the results are reported in Table 5). This works out to (see the right half of Table 5) a loss of Rs. 33.4 crores ($20 m) under a 5% loss, a loss of Rs. 66.8 crores under a 10% loss and a loss of Rs. 133.8 crores if the damage is assumed to be 20%. If the loss is considered to be the additional (social) cost of cotton cultivation in Guntur (and imputed to the 383000 bales grown in 1989/90), the average cost of cultivation of kapas is raised from Rs 651.6 per quintal (see Table 9) to Rs 820.9 per quintal. This represents an increase in the costs of cultivation of 26% for a simulated loss of 5%. For a 10% loss, the cost of cultivation

[5] There is evidence to show that Heliothis populations have increased significantly since the mid eighties, in Guntur (Reddy et al., 1991, Rao et al., 1990). The associated increase in moth migration can increase the pest infestations in other areas manifold. The damage estimates due to increased larval infestation have been based on some unpublished work on pest-yield relationships on pigeonpea and chickpea, by J. Wightman and GVK Rao of ICRISAT.

will go up by 52% and finally, for a 20% crop loss, the costs of production in Guntur will more than double if the externality is taken into account.

Catastrophic Crop Losses

It is amply clear that pesticide overuse in Guntur has made present ecological conditions much more favourable to an outbreak of Heliothis devastation. In other words, the probability of a catastrophic crop loss has increased. Once again there is no hard quantitative evidence regarding the extent of the increase, but by looking at some indirect evidence we put this probability at one in seven[6]. As regards which crop/s is/are most vulnerable to crop failure, evidence from India clearly shows that pulses are the most prone to Heliothis infestations (this may partly be due to the fact that their flowering stage occurs when cotton starts losing its vigour). Regarding the extent of catastrophic damage, it is clear from Indian evidence and evidence from elsewhere that a 50-60% damage is quite feasible. Thus, if it is assumed that there is a field failure on all (and only) pulses, in Guntur and in other

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[6] It is believed (Srivastava et al., 1991, Rao et al., 1990) that rainfall deficit years have a dominant impact on the build up of Heliothis populations but there is no quantitative evidence linking population build up and catastrophic field failures. If we consider the weather data, then from 1980 (when SPs were introduced) to 1989, there have been 7 rainfall deficit years and 2 catastrophic years giving a field failure probability due to high populations of 2/7. From 1960 to 1989 there have been 15 rainfall deficit years thus giving the probability of 1/2 for a deficit year. Hence the probability of catastrophic loss due to SP resistance may be taken as 2/7 x 1/2 = 1/7. Admittedly, this is preliminary and more research is required to get reliable numbers.

areas simultaneously, to the extent of 50% damage, the loss works out to be Rs. 89 crores ($53 m). This gives an expected catastrophic crop loss of almost Rs. 13 crores ($7.8 m). Under the same assumptions as made for the continuing crop losses, this would raise the economic cost of cultivation in Guntur above its private cost by almost 10%.

## VIII. PESTICIDE OVERUSE AND YIELD LOSS WITHIN COTTON

The preceding section has indicated that the external costs associated with pesticide overuse can be very widespread and extremely large. Within the framework of the theoretical model sketched out in Section III, we had emphasised the adoption of the IPM approach to address the problem. In addition to limiting the externality problems, adoption of IPM techniques can lead to efficiency gains within cotton cultivation itself. Thus, in this section we will attempt to quantify the inefficiencies existing in the present cotton cultivation practices and the advantages to be reaped by adopting a package of IPM practices as well as the possible savings in externality costs.

The analysis is based on data supplied by the Pyrethroids Efficacy Group (PEG) India, which has been managing trial plots since 1989/90[7] and collecting statistics on costs of cultivation,

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[7] Indian scientists have been cognizant of the value of IPM techniques in increasing private profitability and in reducing environmental damages since at least the early 70s, when a UN supported IPM program was launched in cotton and rice. However, it appears that the idea of IPM did not gain popularity and the Indian

yield, etc, on the actual farmer fields as well as on the experimental plots (for further details see, Murthy, 1991 and Devaiah, 1990). At the outset it must be stated that the available data is quite meagre (two cotton varieties for two seasons, i.e., a total of four observations) so that the analysis based upon it should be looked upon as being indicative rather than conclusive. As we will see later on in this section the implications of this data are important and underscore the need to augment the present data, by cost of cultivation information from other areas of the district, so that reliability of results is ensured. Nevertheless it is our view (based on personal communications with farmers, agronomists and entomologists plus other indirect evidence) that the results presented in this section will be quite representative and unlikely to be much at variance with the results coming out of a detailed statistical analysis.

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scientists remained mainly preoccupied with issues of purely chemical control. Thus, of the total research funds for cotton, only 5% were directed towards research in IPM strategies (Sudaramurthy and Chitra, 1991). Similarly, in pulses, the bulk of the research was directed towards the breeding of pest resistant plants (Sachan, 1991). In general, development of IPM strategies seems to have been a low priority issue, confined mostly to small scale experimental sites, with little or no propagation of IPM lessons learnt from the experiments.

Recent crop failures (on cotton, pulses and tobacco), in many parts of the country, have changed thinking so that there is now an increased emphasis on designing and implementing IPM strategies for various crops. In fact, the aim of the recent IOPRM/ICAR/USDA joint meeting was to initiate a coordinated, multisite, IPM "action plan" in cotton, so as to fill in existing gaps in knowledge and enable a widespread, all India adoption of IPM.

The PEG Trial Plots

The PEG trial were started in response to the crop attack by Heliothis in 1987/88. Several different plots, each measuring half an acre were demarcated, side-by-side, at Palladigunta, in the heart of the Guntur cotton belt. Different cultivation practices were implemented on each plot such that some predetermined hypotheses could be best addressed. The basic objective of the trials is to demonstrate to the farmer how heliothis can be controlled effectively through the proper use of pesticides in general and SPs in particular. In fact, the trials are also aimed at demonstrating that better management practices in cotton cultivation can substantially reduce pesticide use and increase cotton yields. Thus, the PEG plots have incorporated many of the important elements of an IPM techniques package. The specific practices adopted were:

a) Agronomic practices as recommended by the Andhra Pradesh Agricultural University (APAU), in respect of pre(field) preparation, fertilizer usage, weeding, etc., relevant for the cotton varieties being cultivated. These "optimal" practices were implemented both on the trial plots as well as the fields under traditional farmer practices (the control plots, to be used for comparison purposes).

b) Regular scouting from 40 days after sowing, at 3-5 day intervals, to estimate plant damage, larvae count, egg count, etc.

c) Spraying in accordance with predetermined Economic Threshold Levels (ETLs), i.e., need based use of the pesticide instead of a calender based use as being normally practised by farmers in the Guntur area.

d) Avoiding the use of (broad spectrum) SPs in the early part of the season to preserve the natural predators.

e) Restriction of the use of SPs to between 60-120 days of crop growth, i.e. a window strategy for pyrethroid use. This coincides with the peak flowering and boll formation period of cotton. Furthermore, within the window, 2, 3 and up to 4 SP sprays were tried on the different plots, in an effort to identify the most effective approach.

f) The use of SPs was alternated with conventional pesticides to minimize resistance selection pressures which could arise from the continued use of any one pesticide (refer to Section V).

g) The proper dosage of pesticide was used as well as the proper spray equipment (knapsack sprayer during early stages and power sprayer during the later stages of plant growth).

Some of the important elements of IPM that were not incorporated were:

a) The cultivation of short duration (less than 150 days maturity) and pest resistant varieties.

b) The use of plant growth regulators to control the crop canopy.

c) Better agronomic practices such as split application of fertilizers, to regulate plant growth.

d) Linking the timing of pesticide application to egg count/egg hatch so as to target the Heliothis larvae at their most vulnerable stage.

e) Electrodynamic spray equipment, which is the most efficient for a pattern of small land holdings (Matthews, 1987).

f) Addition of synergists (synergists are chemicals which enhance the potency of pesticides, without contributing to resistance build up) such as neem oil, sesame oil, etc.

Table 6 presents the cost of cultivation data from the PEG demonstration plots. Two varieties of cotton have been used, both hybrids. However, L-389 is whitefly resistant, whereas L-861 is not. The column labelled "actual", contains data from the comparator plots of the area, whereas the columns labelled, Set I, Set II and Set III give the data from the PEG plots, with two, three and four sprays of SPs respectively.

In general, pesticide use is much higher and yields much lower on the comparator plots than for the trial plots. In terms of the per unit costs of cultivation, in two cases, Set III plots are far more efficient than any of the others, in one case they are the same whereas in the last case they are somewhat higher as compared to Set II, the next best alternative for the variety. On average, Set III plots are the most efficient with a cost of cultivation of Rs. 339 per quintal of kapas, which is about 27% less than the actual costs of cultivation, also implying that under the most efficient cultivation practices in this trial profits can go up substantially as compared to the prevalent practices. Additionally, Set III practices are substantially more efficient than the Set I but only marginally more efficient than Set II plots.

TABLE 6: PER HECTARE COSTS OF CULTIVATION ON PEG TRIAL PLOTS AND ACTUAL FARMERS PLOTS

| | LK 861 1989/90 | | | | LK 861 1990/91 | | | | L 389 1989/90 | | | | L 389 1990/91 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SET I | SET II | SET III | ACTUAL | SET I | SET II | SET III | ACTUAL | SET I | SET II | SET III | ACTUAL | SET I | SET II | SET III | ACTUAL |
| #SPRAYS | 13(2) | 12(3) | 11(4) | 16(6) | 15(2) | 14(3) | 13(4) | 19(6) | 13(2) | 13(3) | 13(4) | 22(6) | 13(2) | 13(3) | 13(4) | 22(8) |
| YIELD(KG/HA) | 3000 | 3050 | 3075 | 2500 | 2580 | 3060 | 3425 | 2535 | 2142.5 | 2991.5 | 2770 | 2053.75 | 2787 | 3067 | 3225 | 2440 |
| TOTAL COST(RS/HA) | 9817 | 9990 | 10145.5 | 10472 | 11282.5 | 11560.5 | 11766 | 11035 | 8250 | 9014 | 8831 | 7870 | 11231 | 11483 | 11641 | 14683 |
| PESTICIDE COST(RS/HA | 2297 | 2475 | 2655 | 3632 | 3502 | 3497 | 3325 | 3690 | 3170 | 3547 | 3241 | 2930 | 3904 | 3904 | 3928 | 6503 |
| KAPAS PRICE(RS/KG) | 9.5 | 9.5 | 9.5 | 9.5 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 10 | 10 | 10 | 10 |
| UNIT COST(RS/KG) | 3.27 | 3.28 | 3.30 | 4.19 | 4.37 | 3.78 | 3.44 | 4.35 | 3.85 | 3.01 | 3.19 | 3.83 | 4.03 | 3.74 | 3.61 | 6.02 |
| % PEST.OVERUSE(ACT--UAL, AS COMPARED TO EXPERIMENTAL) | 36.76 | 31.86 | 26.90 | | 5.09 | 5.23 | 9.89 | | -8.19 | -21.06 | -10.61 | | 39.97 | 39.97 | 39.60 | |
| % YIELD INCREMENT | 20.00 | 22.00 | 23.00 | | 1.78 | 20.71 | 35.11 | | 4.32 | 45.66 | 34.88 | | 14.22 | 25.70 | 32.17 | |

AVERAGE (1989/90 AND 1990/91) COSTS OF CULTIVATION PER KG. OF KAPAS

| | SET III | SET II | SET I | ACTUAL |
|---|---|---|---|---|
| LK861 | 3.37 | 3.53 | 3.78 | 4.27 |
| L389 | 3.41 | 3.38 | 3.95 | 5.02 |
| BOTH VARIETIES | 3.39 | 3.46 | 3.86 | 4.62 |

AVERAGE (1989/90 AND 1990/91) % REDUCTION IN COSTS OF CULTIVATION AS A % OF ACTUAL COSTS

| | SET III | SET II | SET I |
|---|---|---|---|
| LK861 | 21.08 | 17.43 | 11.48 |
| L389 | 31.96 | 32.59 | 21.26 |
| BOTH VARIETIES | 26.64 | 25.27 | 16.49 |

AVERAGE (1989/90 AND 1990/91) SAVING IN PESTICIDE CONSUMPTION AS A % OF ACTUAL USAGE

| | SET III | SET II | SET I |
|---|---|---|---|
| LK861 | 18.33 | 18.44 | 20.80 |
| L389 | 24.00 | 21.01 | 25.01 |
| BOTH VARIETIES | 21.52 | 19.89 | 23.17 |

AVERAGE (1989/90 AND 1990/91) IMPROVEMENT IN YIELD AS A % OF ACTUAL YIELD

| | SET III | SET II | SET I |
|---|---|---|---|
| LK861 | 29.10 | 21.35 | 10.82 |
| L389 | 33.41 | 34.02 | 9.70 |
| BOTH VARIETIES | 31.13 | 27.70 | 10.29 |

NOTES: 1) The numbers in brackets refer to the SP sprays, within the "window". In the actual farmers practices a window strategy is not followed.
2) The fact that on the L-389 trial for 1989/90, the farmer is applying 22 sprays and yet spending a smaller amount on pesticides seems to indicate that he is using far less pesticides per application than the required amount.

Source: The data has been drawn from Murthy, 1991. The costs have been appropriately adjusted to take account of pesticide application charges, scouting costs, additional harvesting charges, etc.

## Pesticide Overuse

Since all inputs (such as, fertilizer, seed-bed preparation, weeding, intercultivation, etc.) other than the application of pesticides have been controlled for (identical practices being adopted on the trial and comparator plots), input inefficiency in pesticide use has been calculated as the difference between the actual (comparator) expenditure and that on the experimental plots, as a proportion of the actual expenditure. This varies from an overuse of about 38% to a less than optimal use, of about 21% (see Table 6). Since the average costs of cultivation are the lowest for this group, using the Set III average pesticide expenditure for comparison, we conclude that the prevalent farming practices have led to an excessive expenditure on pesticides to the extent of 21.52%. In other words, if IPM practices as characterized by Set III plots are implemented, pesticide expenditure can be reduced by about 20%[8].

[8] Note that the extent of pesticide overuse is in terms of expenditure on pesticides at retail (farmer) prices. To convert the overuse in expenditure terms to the physical quantity of pesticides, we need detailed information on the prices of the different types of pesticides, number of applications of each by the farmer, the strength of the solutions used, etc. This is a study in itself. For the purposes of this paper, since our emphasis is on costs and benefits of IPM, it seems justified to look at overuse in terms of expenditure.

## Increased Yields

The returns to better crop management can be thought of as accruing in the form of yield augmentation. These range from 2% to about 46% in our sample. The average gain in yield for Set III plots is however, a little over 31% of the actual yield.

## Total Returns to IPM within Cotton

As has already been pointed out, the adoption of Set III type farming practices could result in a cost reduction of about 27% of the actual costs of cultivation. This may be considered to represent the total benefits arising from the adoption of IPM techniques. It must be noted that the cost saving of 27% is likely to represent a lower bound on the benefits of IPM, for at least two reasons. First, not all the constituents of an IPM strategy were adopted on the PEG trial plots and second, the PEG fields under IPM techniques were in the midst of the other farmers' fields, the latter not following IPM practices. This implies the possibility of increased costs of pest control on the PEG plots due to pest migration from the surrounding areas, i.e., the negative pest externalities inflicted on the adopters of IPM by the nonadopters have not been controlled for.

An Estimate of Districtwide Savings in Guntur Cotton from the Adoption of IPM Practices.

On the basis of the above mentioned 20% saving in pesticide expenditure and ± 30% increase in yields, we will quantify the total savings possible in Guntur district as a whole.

The farmers who participated in the PEG trials, typically owned between 3-10 acres of land and practiced rainfed cultivation on black cotton soils[9]. Clearly, the extent of overuse of pesticides will vary with the size of landholdings, education level, financial situation and other socioeconomic characteristics of farmers. We however, do not have information on these aspects and assume that there is an across-the-board, average overuse of pesticides to the tune of 20%.

For the 1989/90 season, it is estimated[10] that Rs. 45 crores ($27 m) of pesticides were used in cotton cultivation in Guntur. With average overuse of 20%, about Rs. 9 crores ($5.4 m) of pesticides are being wasted, which could have been avoided through better crop management techniques.

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[9] In Guntur, agricultural holdings in the range of 3-10 acres constitute 27% of the total number of holdings in the district and comprise 45% of the area. About 45% of the holdings are found in the size class 0.5-2.5 acres and since the size of the PEG trial plots was 1.25 acres, the outcomes are probably quite representative of the district as a whole.

[10] As is true for other agricultural inputs, numbers for pesticide consumption for a particular crop are difficult to come by. The estimated value of Rs.45 crores, has been supplied by a knowledgeable executive of one of the big pesticide companies in India.

The actual cotton lint production in Guntur district for 1989/90 was 383 thousand bales. If better management practices had been instituted there would have been an increased availability of 114,900 bales valued at Rs. 57.4 crores and cottonseed worth Rs. 8.8 crores[11]. The combined loss works out to Rs.66.2 crores and forms about 5% of the agricultural income of the district.

Finally, because of the need for scouting and increased harvesting there are increased labour costs. These work out to about Rs 11.5 crores[12].

The net savings (due to increased cotton output and reduced pesticide input and increased labour costs) of Rs. 63.7 crores (about $38 m), represents an enormous return to better crop management techniques if adopted on a districtwide scale. (The potential problems in adoption of IPM techniques will be discussed in Section XI). Additionally, it must be pointed out that, primarily due to the need for scouting and increased yields, the IPM techniques create a net additional demand for labour.

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[11] Cotton lint price has been worked out as an average of H-4 and MCU-5 prices, weighted in the ratio 40:60. This works out to Rs.2938 per quintal. The data on prices has been drawn from the, "Handbook of Statistics on the Cotton Textile Industry", 22nd edition.

Cottonseed prices have been put at Rs.450 per quintal, which represents about a 5% markup on the 1988/89 prices.

[12] It has been estimated that yields will increase on average by 4.7 quintals per hectare (see Table 9). This requires additional harvesting costs of Rs. 425. Furthermore, scouting costs are Rs. 300 per hectare. With 158000 hectares under cultivation, the total labour costs go up by Rs. 11.46 crores.

## Estimates of Savings on Other Crops in Guntur and All Crops in Other Areas, Due to Adoption of IPM

In Section VII we have presented some simulated estimates of externality losses arising as a result of Heliothis resistance in cotton. The question that arises now is: if IPM techniques are implemented on cotton in Guntur, what is the reduction in external damage that can be expected? For continuing losses, we consider three scenarios--after adopption of IPM, losses are curtailed by 60% (Low or pessimistic alternative), by 75% (Medium alternative) and by 90% (High or optimistic alternative). For the catastrophic losses, it is assumed that the probability will fall by a fourth, i.e., to a value of 1/28.

Table 7 gives the various possible simulated savings in external costs. These range from Rs.20 crores (about $12 m) to Rs. 120.2 crores ($72 m). The "medium-medium" alternative works out to Rs. 50.1 crores (about $30 m).

To sum up: According to the simulations, better crop management within the IPM framework if adopted in the entire district, can lead to several types of benefits, as listed under:

a) A total reduction in pesticide use to the tune of about Rs.9 crores ($5.4 m),

b) An increase in cotton production (lint and seed) of about Rs.66 crores ($40 m),

c) A reduction in the externality costs, due to management of pest resistance, to the extent of about Rs. 50.1 crores ($30 m),

TABLE 7: SIMULATED REDUCTION IN EXTERNALITY COSTS THROUGH IPM IN COTTON (RS. CRS.)

| CONTINUING EXTERNALITY (RS.CRS) | | DEGREE OF CONTROL LOW 0.6 | MEDIUM 0.75 | HIGH 0.9 |
|---|---|---|---|---|
| | | (RS.CRS.) | | |
| LOW | 33.4 | 20.04 | 25.05 | 30.06 |
| MEDIUM | 66.8 | 40.08 | 50.1 | 60.12 |
| HIGH | 133.6 | 80.16 | 100.2 | 120.24 |
| TOTAL SAVINGS (INCLUDING SAVINGS IN CATASTROPHIC COSTS) | | | | |
| | | (RS.CRS.) | | |
| LOW | | 29.54 | 34.55 | 39.56 |
| MEDIUM | | 49.58 | 59.6 | 69.62 |
| HIGH | | 89.66 | 109.7 | 129.74 |

d) A reduction in various direct costs of environmental degradation due to reduced use of pesticides.

a) and b) accrue as direct monetary benefits which result in a substantial increase in cotton farmers profits. c) accrues as an increase in the profits of other crops which are affected by the externality. Finally, d) represent non market social benefits and we now turn to a fuller discussion of this aspect.

## IX. DIRECT ENVIRONMENTAL COSTS OF PESTICIDES

In this section we will take a brief look at some of the direct environmental costs arising from pesticide use in the Guntur area. It must be stated that no quantification will be attempted and the discussion is merely intended to focus attention on the possible existence of these costs. However, the discussion of the next section points to the urgent need to quantify these externalities.

There are several ways in which the use of pesticides creates environmental problems. These are:

a) Hazards to human beings in the process of storage, disposal and the spraying of pesticides.

b) Hazards to other mammals through pesticide drift, especially into the wooded/forested areas.

c) Killing off of nontargetted species such as birds, honey bees and other beneficial predators.

d) Run off via irrigation or wash off via rain, of the pesticides into fish-bearing waters.

e) Leaching of pesticides into the soil and contamination of the ground-water table.

Table 8 below lists the most commonly used pesticides in cotton and the associated toxicity ratings[13].

In terms of all India consumption of these pesticides in 1988, it is found that fenvalerate, cypermethrin and monocrotophos rank first, second and third respectively (Jackson, 1991). It may also be noted that under the Bank's Operational Directive 4.3 each of the pesticides mentioned in Table 8 are eligible for funding by the Bank although some would be restricted.

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[13] These toxicity classifications are based on trials conducted under controlled laboratory conditions and thus can be different from toxicity impacts in the field. For example, SP molecules are so strongly adsorbed to soil particles that they merely pass through the digestive system, without harming the organism.

TABLE 8: COMMONLY USED PESTICIDES AND THEIR TOXICITY

| PESTICIDE | ORAL TOXICITY | DERMAL TOXICITY | TOXICITY TO BIRDS | HONEY BEES | TOXICITY TO FISH |
|---|---|---|---|---|---|
| PYRETHROIDS | | | | | |
| FENVALERATE | XX | X | - | XXX | XXX |
| CYPERMETHRIN | XX | X | 0 | XXX | XXX |
| DELTAMETHRIN | XX | X | XX | XX | XXX |
| OTHERS | | | | | |
| MONOCROTOPHOS | XX | XX | XXX | XXX | XXX |
| ACEPHATE | X | X | - | - | X |
| ENDOSULPHAN | XX | XX | - | - | XXX |
| CHLORPYRIPHOS | XX | X | - | XXX | XXX |
| DIFLUBENZURON | XXX | XX | XXX | XXX | X |
| PHOSPHAMIDON | XXX | XX | XXX | XXX | X |
| DIMETHOATE | XX | XX | XXX | - | X |
| CARBARYL | X | X | X | XXX | X |

Source: A.J. Shaw, Cotton Pesticides Guide 1991-92 NSW Agriculture.

- \- No Information
- XXX Highly toxic
- XX toxic
- X Low toxicity
- 0 Non toxic

Note that oral and dermal toxicity refer to mammalian toxicity. Pesticide residues in fish could lead to toxicity in humans.

## Morbidity Costs of Pesticides

From Table 8, it can be seen that the three most widely used pesticides have low dermal toxicity and somewhat higher oral toxicity. There is sufficient qualitative evidence to indicate that farmers do not use pesticides in accordance with the safety requirements. For example, pesticide containers may be washed in the local stream and used to store household goods, little or no protective clothing (e.g. gloves, face masks etc.) are worn during handling and spraying pesticides, etc. (Pingali and Marquez, 1990). Thus, while no quantitative estimates exist, the morbidity costs arising from the unsafe use of pesticides are likely to be quite substantial, especially given the fact that at least a quarter of a million cotton farmers use pesticides in the Guntur area alone.

Other Non Market Environmental Costs

As indicated in the above table, it is clearly the case that the three most widely used pesticides are highly toxic to honey bees and fish. As regards toxicity to fish, since these pesticides biodegrade quite rapidly (within 7-10 days, Jackson, 1991) and most of the area under cotton is rainfed and the water sources are far from the cultivated fields, the potential for irrigation runoff into fish bearing waters is somewhat limited. Similarly, due to the fact that the water table is very low in this area the contamination of the ground water due to leaching of pesticides is likely to be unimportant.

As regards toxicity to honey bees (and other insects), the excessive use of these broad spectrum pesticides can trigger off two negative externalities. First, they can cause an outbreak of secondary pest damage by disequilibrating the predator-prey chain. As discussed by Harper and Zilberman (Harper and Zilberman, 1989), secondary pest damage can be quite substantial in the case of

Imperial Valley cotton. For the Guntur area there is no evidence (ICRISAT entomologists, PEG entomologists, pers. com.) of a secondary pest being kept under check by natural predators and, therefore, this potential external cost is likely to be unimportant.

The second type of externality, attributable to the use of broad spectrum pesticides refers to the resurgence of the primary (target) pest, resulting from the unintended destruction of natural predators, the latter being susceptible to the same pesticides as the targetted pest. Using simulation models, one line of research (Zavaleta and Ruesink, 1980 for alfalfa and Reichelderfer and Bender, 1979 for soyabeans) finds that these external costs can be substantial. On the other hand, another set of researchers (Fitt, 1989) conclude that the role of key beneficial organisms (Trichogramma spp., and microplitis) in controlling H. armigera populations to below economically damaging levels is, at best, uncertain. They conclude that, especially in the tropical areas, "evidence for a regulatory function of beneficial organisms at the regional level is sparse for phytophagus insects in general, but especially for Heliothis spp. .....it seems probable that the regional abundance of Heliothis is determined more by climatic (abiotic) factors, ...., than by biotic factors."

Whatever be the weight of the evidence from other countries, it is widely accepted that in India, one of the important reasons for the 1987/88 cotton crop failure (and continuing yield losses subsequently) is because of the destruction of beneficial predators through cumulative overuse of pesticides[14]. What could be the possible extent of this loss? Unfortunately, since there is no hard evidence on the regulatory role of beneficials in this region, we are unable to quantify this external cost.

One more externality may be mentioned here. There is evidence to indicate that SPs, especially cypermethrin, stimulate the egg laying capacity of aphids and white fly, thus exacerbating the primary pest pressure (Stan Nemec, pers. com.). Once again, no quantitative estimates exist, but since white fly damage has been a major problem in this area, it is possible that this negative externality has been quite large.

## X. THE IMPACT OF PESTICIDE EXTERNALITIES ON INTERNATIONAL TRADE IN COTTON.

In view of the increasing attention being paid to environmental problems, it has become important to look at the connection between international trade and domestic and transnational environmental issues. It has been pointed out that long staple cotton has the potential for earning substantially greater amounts of foreign exchange than at present. This is because of the existence of restrictive export quotas, which also keep the domestic price below the international prices. Based on the direct and indirect costs of cultivation, it has been found

[14] Some of the beneficial predators which are especially vulnerable to SPs are, beetles (M.sexmaculata), lacewing (C. Carnea) and spiders (Oxyopes spp.), (Jayaraj et al., 1991).

(Gulati, Hanson and Pursell, 1990) that cotton could be an important export crop from India. However, we also need to incorporate the costs arising due to externalities, to estimate its full economic costs of production, so that a proper consideration of cotton as an export earner and as an import substitute can be made. Before we propose policy instruments to internalize the externalities in Guntur cotton production and reassess the export potential and import substitution potential of cotton, a quick survey of the existing literature in the area is in order.

The general thrust of recent research (especially the research emanating from within the Bank) has been to examine the effect of trade liberalisation policies for small economies on domestic as well as foreign environmental quality (Lutz, 1990). The theoretical results coming out of these studies are naturally sensitive to the assumptions of the model in question (see also, Anderson, 1991) and so also the empirical results. Furthermore, contrasting these with other empirical studies (Binswanger, 1989, Mahar, 1989) which look at domestic environmental degradation, it appears that changes in domestic policies have far greater impacts on the environment than do trade policies. This is not a surprising result since the impact of trade policies on the environment is likely to be diffuse and somewhat roundabout whereas domestic policies are likely to directly and strongly affect the environment. In terms of policy, clearly, the use of trade policy measures to improve the quality of the environment will be a second best solution. It is only in the case of transnational environmental problems that trade policy as a solution can become a first best candidate, e.g. world ivory trade and the related problem of extinction of wild elephant herds (but see Baumol and Oates, 1988).

As distinct from the above approach, it is also important to examine the trade-environment nexus from the other end, i.e., how do the existing patterns of trade get altered if existing environmental standards are made more stringent or, if new environmental regulations are enforced? Two recent papers (Tobey, 1990, Low, 1991), have looked empirically at the impact of environmental standards on trade patterns. Tobey concludes that, "... in no case is there any evidence that the introduction of environmental control measures has caused trade patterns to deviate from HOV (Heckscher-Ohlin-Vanek) predictions". Two points may be noted. First, for several reasons that he himself points out, Tobey's results are indicative rather than conclusive. Second, only industrial manufactures have been considered for the analysis.

Low reaches the same conclusion (viz. that environmental stringency does not affect the volume and pattern of trade to any appreciable extent) by simulating the pattern of US-Mexico trade, after incorporating the costs of pollution control by Mexican industry. Note that in this study also only trade in industrial manufactures is considered.

As distinct from the preceding research, in this section we will examine the impact of environmental regulation on the trade in <u>agricultural</u> commodities. The analysis will be in terms of the <u>changes in production costs</u> arising from the introduction of environmental regulations. Specifically, we will address the question of what happens to comparative advantage and international trade in cotton, from India, if the misuse of pesticides in cotton cultivation is corrected for. The analysis of the following subsections assumes that quantity restrictions on the exports and imports of cotton continue to be in effect in India. This implies that domestic prices will be determined primarily by domestic demand and supply conditions. (With no quantitative restrictions on trade in cotton, the domestic price to producers will be equal to the fob/cif prices plus export subsidies/import duties, minus whatever domestic externality tax is imposed. In that case it would be redundant to predict price changes as a result of changes in domestic policies since these will move up and down with world prices and the exchange rate).

We shall examine the outcome under two different hypothetical policy prescriptions. Under the first policy prescription, the externalities are sought to be internalized via the imposition of appropriate (appropriateness as suggested by the theoretical model) taxes in cotton cultivation. Under the second scenario, the externality problem is sought to be corrected by imposing an appropriate tax to correct the externality, remaining after the implementation of IPM techniques in cotton.

## Non Adoption of IPM and Competitiveness of Cotton

If IPM techniques are not adopted but we try to address the externality problem by means of appropriate taxes, what is the impact on cotton as an exportable and as an import substitute crop? This question had been posed at the beginning of this report and we seek to examine it now. Based on a knowledge of the Nominal Protection Coefficients (NPCs), Andhra Pradesh long staple cotton has been shown to be an efficient export crop as well as an efficient import substitute (Gulati, Hanson and Pursell, 1990)[15]. The average NPC for the eighties (1980/81-1990/91) is 0.57 under the exportable hypothesis and 0.54 under the importable hypothesis (Kishor, 1991). Assuming that domestic prices approximate marginal production costs, domestic prices could rise by about 75% before marginal costs would exceed the farmgate export prices at the official exchange rate. Similarly, domestic cotton prices would have to rise by more than 85% for cotton to stop being an efficient import substitute.

From the simulation exercise of Section VII, we had seen that externality losses (continuing plus catastrophic) due to increased pest resistance could increase the costs of cultivation of Guntur cotton by 36%, or 62%, or 114%. Recall that results of the theoretical model had suggested that the first best solution to address these externalities was to impose a tax on the pest population on each farmers field and to impose a tax on pesticides

[15] NPC is the ratio of domestic prices to international prices, adjusted for international and domestic transport costs. The coefficient under the exportable hypothesis is higher because shipping costs are deducted from world prices before comparison with domestic prices, whereas under the importable hypothesis shipping costs are added to the international prices. Also note that the NPCs refer to kapas which includes cottonseed and cotton lint. Since cottonseed is quite protected, the protection coefficients for lint alone will be smaller.

going into cotton cultivation. Since it is unrealistic to impose a tax on the pest population, the second best alternative was to impose a tax on an input which was likely to be an important determinant of the pest population, for example, fertilizer inputs. Hence a second best strategy to internalize the externalities is to levy taxes on fertilizer and pesticide inputs into cotton cultivation[16]. (The practicality of implementing these taxes is taken up in Section XI).

With the hypothetical imposition of fertilizer and pesticide taxes and the assumption that cotton farmers maintain their absolute per unit profits at the existing levels, the supply curve for cotton will shift up by 28% or 49% or 90% (of the prevailing price), corresponding to the simulated externalities which raise costs of cultivation by 36% or 62% or 114% respectively[17]. What will be the effect on the final price of cotton? There are two possibilities:

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[16] The nominal protection coefficient for pesticides has been provisionally estimated to be 1.3. This suggests that Indian cotton farmers are possibly being implicitly taxed 30% as compared to world prices of pesticides. This estimate is preliminary and more work needs to be done to get a reliable number. Note also that the domestic prices used in the estimation reflect those charged for the "standard" brands. There also exists a fairly large (15-20% of market share) market for "non-standard" products, supplied by small scale pesticide formulators whose prices are 20-30% lower. However by purchasing these products a farmer also runs the risk of getting totally spurious or diluted products.

[17] An average price of Rs. 827 per quintal of kapas has been used for the calculations. Thus for a 36% increase, the new costs of cultivation become Rs. 886.2 per quintal (= 1.36*651.6). Adding the existing profit margin of Rs. 175.4 per quintal (= 827-651.6), gives a supply price of Rs. 1061.6. This implies an increase of 28% over the market price of Rs. 827 per quintal, etc.

a) If the supply curve for cotton is perfectly elastic (with a downward sloping demand curve), the extent of the upward shift in the supply curve will be fully passed on as a price rise, i.e., cotton prices are likely to rise by 28% or 49% or 90%, under the three scenarios respectively.

b) If the supply curve for cotton is upward sloping (with a downward sloping demand curve), the extent of the final price rise will be less than the shift in the supply curve since part of the tax burden will be borne by the cotton producers. The extent by which final prices rise will depend upon the elasticities of the demand and supply functions. (Clearly, in order to determine the changes in final prices, the demand and supply curves for Guntur cotton must be estimated).

There is another effect that we need to point out. The imposition of these taxes is likely to lead to a change in the profitability of cotton relative to other crops. This may lead to intercrop substitutions. A detailed analysis in a "competing crops framework", (Gulati and Sharma, 1991) to quantify these changes cannot be attempted here but the extent of the shift will depend upon the elasticity of substitution between cotton and other crops. While reliable estimates are difficult to obtain, for the Guntur area, chillies, tobacco, groundnuts and pulses are the possible substitutes. Reduction of area under cotton is likely to lead to an additional rise in cotton prices.

What is the impact of these effects on cotton as an export crop and as an efficient import substitute? The first two damage simulations suggest that cotton prices are likely to rise at most by 28% or 49% respectively. Thus, cotton is likely to contine being an efficient export crop and an efficient import substitute.

However, if the externality damages are hypothesised to be large so that the supply curve is shifted up by 90% (of the prevailing market price), then cotton ceases to be an efficient export and an efficient import substitute, if the supply curve is perfectly elastic. On the other hand, if the supply curve is upward sloping then we need reliable estimates of the demand and supply elasticities before we can estimate the extent of the rise in price and judge the status of cotton as an export and an import substitute[18].

Implementationion of IPM and the Impact on Efficiency of Cotton Exports and on the Efficiency of Import Substitution

On the basis of the average reduction in pesticide use and the increase in yield, referred to in Section VIII, we try to calculate the impact on the costs of cotton production for the district, on average, when IPM techniques are adopted. The Guntur Cotton Report, 1990, gives the average cost of cultivation per hectare for the

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[18] It must be kept in mind that we have not considered the direct environmental costs of the sorts mentioned in Section IX, in the above discussion. It is possible that these costs are large enough to alter the above conclusions, when we try to internalize them through additional taxation. Research is urgently required to quantify these costs.

In addition, the "second-round" price effect arising because of intercrop substitutions have not been factored in. Again, since these impacts are potentially important, research is necessary to quantify this effect.

prevalent farmer practices, for rainfed cotton in the district. Some items of expenditure have been updated to reflect current costs. These are, spraying charges, pesticide expenditures and estimated average yield. The updated average costs of cultivation are presented in Table 9.

What will be the effects on costs of cultivation of adopting an IPM strategy? The changes resulting from the adoption of the new technology can be listed as:

a) Reduction in pesticide costs,

b) A reduction in the number of pesticide sprays and therefore a reduction in associated labour and material charges,

c) Because scouting is an integral part of IPM, there are labour and material costs to be incurred on this account,

d) There may be increased material costs associated with the usage of better spray equipment,

e) Since yields go up, higher expenditures have to be incurred on harvesting and marketing activities.

In Table 9, we have tried to incorporate the above mentioned aspects when calculating the costs of cultivation under the IPM techniques.

From Table 9, it can be seen that under traditional practices, pesticides costs form about 28% of total costs and comprise the largest individual item of expenditure. The second largest item of expenditure and the biggest item of labour costs is harvesting charges. This forms almost 14% of the total costs of production. With cultivation under IPM techniques, pesticide costs are still

TABLE 9: AVERAGE COST OF CULTIVATION OF RAINFED COTTON, 1989/90.

| ITEM OF EXPENDITURE | ACTUAL RS./HA. | ACTUAL % | IPM RS./HA. | IPM % |
|---|---|---|---|---|
| LABOR CHARGES | | | | |
| Preparatory Cultivation | 240 | 2.3 | 240 | 2.5 |
| Tractor Charges | 250 | 2.4 | 250 | 2.6 |
| Sowing Charges | 100 | 1.0 | 100 | 1.0 |
| Weeding/Intercultivation/ Fertilization Charges | 600 | 5.9 | 600 | 6.2 |
| Spraying charges | 855 | 8.4 | 650 | 6.8 |
| Harvesting Charges | 1413 | 13.8 | 1837 | 19.1 |
| Scouting Charges | 0 | 0.0 | 300 | 3.1 |
| COST OF INPUTS | | | | |
| Seed | 100 | 1.0 | 100 | 1.0 |
| Farmyard manure | 600 | 5.9 | 600 | 6.2 |
| Chemical Fertilizers | 1300 | 12.7 | 650 | 6.8 |
| Pesticides | 2850 | 27.9 | 2280 | 23.7 |
| LAND LEASE TAXES | 1500 | 14.7 | 1500 | 15.6 |
| HIRING OF MACHINERY | 120 | 1.2 | 120 | 1.2 |
| MARKETING CHARGES | 302 | 3.0 | 393 | 4.1 |
| TOTAL | 10230 | | 9620 | |
| YIELD (QTLS./HA. KAPAS) | 15.7 | | 20.41 | |
| COST PER QUINTAL | 651.6 | | 471.3 | |
| REDUCTION IN COST | | | | 27.7 |

NOTES: 1) The actual farmer practice is to go in for 19 pesticide sprays, on average. Under IPM an average of 13 sprays per season are needed. Spraying costs Rs.50/hectare, including fuel. Under traditional practice, it is assumed that spraying costs 10% less.
2) Harvesting or the picking of Kapas costs Rs.90 per quintal.
3) Under IPM techniques, scouting is carried out between 40 to 140 days of crop growth at 5 day intervals thus needing 20 scouting sorties each of which requires half a day of labor time. Wages of agricultural labourers are Rs.20/day. A skill charge of Rs.5 per day is added. A charge of Rs.50 is added for cost of pegboards and other materials
4) Based upon the PEG trials data, under the IPM strategy, yield has been increased by 30% and pesticide expenditures reduced by 20%.
5) The consumption of chemical fertilizers is reduced by 50%. This is consistent with the findings of several studies (APAU, recommended practices, Subba Rao et al., 1987).

Source: The basic cost of cultivation data is from, "The Guntur Cotton Report, 1990". However, some items of expenditure have been updated.

the largest single component of expenditure, but now form about 24% of total costs. Due to an increase in yield, harvesting costs go up substantially to constitute about 19% of total costs. As a result of these changes, the per unit costs of production of kapas fall from Rs.652 per hectare to Rs.471. This represents an average cost reduction of 28%, over the present average costs of cultivation. In addition, implementation of IPM will also reduce the negative externalities (of the sort, described in Sections VII and IX of this report) and lead to a substantial savings in costs overall. Thus, implementation of environmental policies generates gains in cotton production as well as in environmental quality. This is in contrast to the results in Tobey (Tobey, 1990) and Low (Low, 1991), where an improvement in the environmental quality is achieved at the expense of costs of production and negative impacts on comparative advantage, which could be potentially significant.

With a fall in the costs of production by 28%, the supply curve of cotton is likely to shift downward. What is the plausible extent of this shift? Under the same assumption, of a fixed absolute profit margin, as made in the previous subsection, the extent of the downward shift is likely to be about Rs. 180 per quintal of output or about 22% of the prevailing price.

To see what happens to the status of cotton as an export and as an import substitute we need to consider how the externality costs change as a result of implementation of IPM. Table 10 is based on the information contained in Table 7 and gives the simulated externality losses which are likely to remain even after the adoption of IPM practices. Imputed back to the cotton cultivation in Guntur, these "residual' externalities could raise the costs of cultivation by between 5% and 49%. If these are sought to be internalized through a pesticide tax[19] the supply curve for cotton will shift up. Table 10 gives the possible extent of the upward shift in the supply curve under the different simulations of residual externalities. The upward shift ranges from Rs. 26 per quintal to Rs. 221 per quintal.

The lowest panel of Table 10 gives the net shift in the supply curve for cotton (downward shift due to implementation of IPM <u>net</u> of the upward shift due to a pesticide tax). It can be seen that in all cases except one, there is a <u>net downward</u> shift of the supply curve (as indicated by a negative sign), implying that the status of cotton as an efficient export crop and an efficient import substitute is enhanced. In other words, addressing the externality issue via implementation of IPM and a pesticide tax appears to give cotton a pro trade bias.

In only one ("high-high") case, when the pesticide tax shifts the supply curve upward by Rs. 221 per quintal, is there a net upward shift of the curve, by about Rs. 40 per quintal. Since this could increase the pre-policy-change-price (of Rs. 827 per quintal)

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[19] Recall that another important implication of the theoretical model was that since it directly controls the pest population, IPM could be a potential first best instrument, in lieu of a tax on the pest population. Thus the policy package suggested by the model included the implementation of IPM together with a tax on pesticides.

TABLE 10: SIMULATION OF "RESIDUAL" LOSSES POST IPM ADOPTION

| EXTERNALITY RS. CRS | | DEGREE OF LOSS LOW 0.1 | MEDIUM 0.25 | HIGH 0.4 |
|---|---|---|---|---|
| | | | RS.CRS. | |
| LOW | 33.4 | 3.34 | 8.35 | 13.36 |
| MEDIUM | 66.8 | 6.68 | 16.7 | 26.72 |
| HIGH | 133.6 | 13.36 | 33.4 | 53.44 |
| CONTINUING LOSSES INCLUDING CATASTROPHIC LOSSES (RS.CRS.) | | | | |
| LOW | 33.4 | 6.54 | 11.55 | 16.56 |
| MEDIUM | 66.8 | 9.88 | 19.9 | 29.92 |
| HIGH | 133.6 | 16.56 | 36.6 | 56.64 |
| IMPLIED INCREASE IN COSTS OF COTTON CULTIVATION (%) | | | | |
| LOW | | 5.41 | 9.55 | 13.70 |
| MEDIUM | | 8.17 | 16.46 | 24.75 |
| HIGH | | 13.70 | 30.27 | 46.84 |
| IMPLIED UPWARD SHIFT IN THE SUPPLY CURVE (RS./QTL.) | | | | |
| LOW | | 25.49 | 45.02 | 64.55 |
| MEDIUM | | 38.51 | 77.57 | 116.63 |
| HIGH | | 64.55 | 142.66 | 220.78 |
| IMPLIED NET SHIFT IN THE SUPPLY CURVE (RS./QTL.) | | | | |
| LOW | | -154.81 | -135.28 | -115.75 |
| MEDIUM | | -141.79 | -102.73 | -63.67 |
| HIGH | | -115.75 | -37.64 | 40.48 |

at most by 5%, cotton continues to be an efficient export and an efficient import substitute.

Similar results have been achieved in other countries (for example, rice in Indonesia, cotton in Texas and in Zimbabwe), so that implementation of IPM practices has improved the environment and reduced costs of cultivation. Thus, on the basis of evidence presented in this report, supported by cross-country evidence, it seems that the adoption of such policies should be strongly recommended.

Summary

In this section we have looked at the impact on trade in cotton (assuming the continuation of quantitative restrictions on cotton trade) under two hypothetical policy prescriptions aimed at internalizing the externalities. Under the first alternative fertilizer and pesticide taxes were imposed on cotton, necessary to handle the external costs. It was found that in two of the three simulated estimates of external damages, the status of cotton as an export crop and an import substitute was likely to remain unchanged. But in the case that the "high" estimate was considered cotton was likely to stop being an efficient export and an efficient import substitute (remember that to get a clearcut answer it was essential to have estimates of the demand and supply elasticities).

Under the second policy prescription, IPM was hypothetically implemented in cotton and the residual externalities were taken care of by a pesticides tax. It was found that under all plausible externality cost estimates, this resulted in a "win-win" situation since cotton remained (or became more) competitive and domestic externality costs were significantly reduced. One major difference between the two approaches was that the efficiency gains within cotton available under IPM were left largely unexploited under the second approach.

In sum, given the basic objective of correcting the externalities generated in the process of cotton cultivation, implementation of an IPM program seems to be the best strategy.

## XI. CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

### Summary and Policy Recommendations

In this report we have pointed out the most important externalities arising in the process of pesticide use in cotton cultivation in a theoretical framework. Then, a preliminary quantification has been attempted for some of them. Some of the important points emerging from the analysis are:

a) According to the PEG trials, there is an overuse of pesticides to the extent of 20% annually, as compared to the present usage levels, in terms of expenditure on pesticides.

b) Under one of the simulated scenarios[20], annual externality costs (damage to non cotton crops in Guntur and all crops in the other potentially affected districts) could be as high as Rs. 66.8 crores ($40m). This implies an increase in the costs of cotton cultivation by 52% of existing costs and would require an offsetting price increase of about 41%.

c) Since overuse of pesticides has raised the resistance level of the pests, the annual expected value of catastrophic losses due to "complete" crop failure could be about Rs. 13 crores ($7.8m). This implies an increase in the costs of cotton cultivation by almost 10%. (Again, note that empirical research to improve this estimate is needed).

d) Better crop management techniques associated with the adoption of IPM practices can raise yields in cotton by 30%.

e) From the perspective of international trade in cotton, plausible simulations suggest that if the externalities are sought to be internalized (via suitable taxes only, or via IPM plus taxes), cotton would continue to be an efficient export crop as well as an efficient import substitute under most of the simulated externality cost scenarios. However, this conclusion assumes that the direct environmental costs (of the sorts discussed in Section IX) are not "too large". (This aspect also needs further research).

The report has highlighted the point that theoretically, an efficient way to address the externalities problem is via the

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[20] These are really guesstimates and empirical research to obtain reliable <u>estimates</u> of the externalities is urgently required.

implementation of IPM techniques (together with a tax on pesticide input, if required). Empirically, it seems likely that by implementing IPM practices in cotton, costs of cultivation can be reduced by 28% on average, over the present costs of cultivation and result in annual net savings of $38 m. In addition, the externality costs can be reduced by about $30 m annually, under one of the simulations. It has also been shown that adoption of IPM techniques create a net additional demand for labour which is appropriate given the ample supply of low cost labour in the cotton growing areas.

Having demonstrated the many benefits that can accrue from the adoption of IPM techniques, it is important to look into steps for its implementation and the possible pitfalls in the course of its adoption.

The heart of any successful IPM program is an efficient scouting service, provided by a pest control specialist (Van Bosch, 1980). The pest control specialist has to be well versed in the practical aspects of crop-sampling to monitor the pest population, to relate it to ETLs (Economic Threshold Levels) and then to advise the farmer if pesticide spraying is required. On large farms it is possible (and often usual) for pest densities to differ on different parts of the farm. This implies that the same farmer may have to follow different pest control strategies in different parts of the same farm. Furthermore, IPM is a dynamic evolving concept. As new information becomes available, ETLs may need to be revised, dosage, mix and timing of pesticides may be changed, frequency of scouting may be modified, etc. By constantly evaluating the situation and deciding strategies as conditions dictate, the pest control specialist imparts flexibility in decision making. It is this flexibility and dynamism that sets off IPM from the conventional pest control program. In the latter case, pesticides dominate the system and are used as prophylactics. Under IPM, the specialist undertakes an ongoing assessment of the agroecosystem and the dynamic interplay of plant, climate, local cropping patterns, pest resistance, predator-prey relationships, secondary pests, etc., to optimize the use of pesticides.

The term "specialist" is used deliberately to emphasize the fact that monitoring/scouting services are a high skill requirement and can be effectively performed by (to reiterate) well qualified and well trained personnel. Thus, in parts of the US, where the IPM approach has been successful, in large measure it has been due to the availability of graduates of agricultural departments who have hired themselves out as pest control specialists to farmers. These consultants usually work for a number of farmers in a particular area, in an independent capacity.

How feasible is it to implement IPM practices in India?[21] Several aspects crop up in this context. First, since the IPM package is akin to a new agricultural technology, there is likely to be strong resistance to its adoption by farmers. It has to be

[21] We had pointed out earlier that the concept of IPM is not new to Indian scientists and its benefits are well appreciated by agricultural experts. Also, now, there are serious attempts to initiate IPM techniques at a coordinated, all India level.

extensively demonstrated that the returns under IPM practices are substantially higher than under the traditional practices (ergo the importance of PEG experiments of the type described in Section VIII of this report). Since, for the individual risk averse farmer it is possible that prophylactic spraying of pesticides reduces the risk of crop failure (i.e., pesticides act as an insurance against crop failure, Feder, 1979) it must also be demonstrated to the farmer that IPM techniques are at least no more risky than the traditional practices or that the increased returns far outweigh any increase in risk, otherwise he will not adopt the new practices[22]. Furthermore, although IPM practices reduce the possibility of catastrophic crop failures ( because of proper resistance management), a myopic decision maker will neither perceive that benefit nor therefore see the wisdom of adopting IPM. For a variety of reasons, farmers in the Guntur area are believed to care mainly about current season profits and to discount the future very heavily. If the farmer is to be persuaded to go in for the IPM techniques, large scale education and dissemination of information is probably necessary.

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[22] The question that is often raised is, "why, despite their high cost saving impacts, are IPM techniques not widely adopted by farmers?" The answer may have to do with the <u>quality</u> of the available scouting services. In the case of the experimental plots (from which evidence is cited), scouting is supervised by well-trained scientists. It is more than likely that the average farmer does not have faith in the scouting "specialist" that he has access to. In other words, although the returns under IPM are higher, the farmer perceives the variance (risk) associated with the new technique to be extremely high, due to poor quality scouting services. Thus the average farmer is unwilling to go in for IPM practices. However, this point needs empirical investigation.

Once the farmer has been persuaded to go in for the new technology, will a market based system for the provision of scouting services succeed? Recall that the average size of the farm in this area is about one acre. Thus, as distinct from the US (where different parts of one large farm are likely to be sufficiently heterogeneous to warrant different pest control strategies), several contiguous farms in India are likely to be sufficiently homogeneous to warrant the same resistance management strategy. In other words, there is a possibility of farmers free-riding the services of a pest control specialist and the noncooperative solution would be one where too few (no) specialists are hired. In this context, free-riding refers to a situation where (say) only one farmer actually pays to get a scouting expert but his neighbours take their cues from him (regarding the need for and the timing of pesticide application) and thus get the benefits of the scouting service without paying for it. How realistic is this possibility? It would appear that even on contiguous plots of small size, conditions are likely to be different enough to require different strategies, so that if farmers try to free-ride they will not be able to reap the full potential of IPM (IOPRM team members, pers. com.). Nevertheless, it is not difficult to think of other noncooperative behaviours which are individually rational but result in a socially non optimal equilibrium (i.e., too few specialists are hired). Thus, it may be preferable to look at cooperative solutions. That cooperative solutions are practical is shown by the experience of cotton farming in Zimbabwe. There, the large scale farmers cooperatively supported an institute (the Cotton Training Centre near Kadoma, Zimbabwe) where they could learn sophisticated scouting techniques (Kiss and Meerman, 1991). The poorer small scale farmers, with their lower literacy and numeracy, however, had to have a separate training scheme.

The potential problems in getting farmers to adopt IPM techniques point to the probable need for large-scale government inputs into farmer education and extension work. For example, there may have to be a centralized provision of high quality scouting services especially to the poorer category of farmers. Additionally, some sort of crop insurance scheme may have to be offered to farmers to persuade them to try the IPM approach. Emphasis must be given to voluntary participation by the farmers in the program. Once the benefits have become transparent, the number of adopters is likely to escalate and once enough farmers get trained the program could become self generating and self supporting. (The adoption of IPM in rice in Indonesia is a well documented success story which proceeded along these lines. Also see Kiss and Meerman, 1991, for several case studies dealing with the actual implementation of IPM techniques in Africa).

The second substantive issue is concerned with the types of taxes that can be used to internalize the externalities in cotton cultivation. Within the framework of the theoretical model we had seen that one second best policy option to address the problem was to levy taxes on fertilizer and pesticides. Another option was to implement IPM and levy pesticide taxes. Strictly speaking, pesticide/fertilizer taxes have to be levied on the inputs going into cotton cultivation in the Guntur area. Given that several other crops are grown at the same time as cotton (rice, chillies and tobacco) and require pesticides and fertilizer as inputs, it is impossible to earmark the quantities going exclusively to cotton. The next best alternative would be levy taxes on fertilizers and pesticides per se, i.e., on an all India basis, irrespective of input by crop. This may not give us the desired outcome since the costs of cultivation for all crops will be raised in accordance with the share of these inputs in their total costs. However, since the share of pesticides in total costs of cultivation is the highest in cotton (and substantially higher than for rice, the next most pesticide intensive user), a pesticide tax may be the least inefficient among input taxes.

Although, in the framework of our theoretical model, a cotton output tax appears to be inferior to a pesticide or a fertilizer tax, we may consider it if it is administratively more convenient. The answer is in the negative since a tax on Guntur cotton output poses its own problems. Basically, farmers will try to evade the tax by selling their output in the bordering states of Karnataka or Maharashtra. The extent of the evasion will depend upon the size of the tax and the costs of transportation.

The preceding discussion has pointed out that taxation as a means to correct for externalities, needs careful consideration since it is likely to be a rather blunt instrument for the reasons cited above.

Can direct regulation be more efficient in internalizing the externalities? For example, would a law that pyrethroids be used for a certain maximum number of times at a certain time in the growing season to reduce resistance pressures (the window strategy) be enforceable? For a variety of reasons (pyrethroids are substantially cheaper than conventional pesticides, there in a significant small scale pesticides industry over which the authorities have little control, the possibility of smuggling pesticides from other states, myopia of decision making among farmers, etc.), it is unlikely that direct bans will be very effective in tackling the externalities issue.

If taxation and direct regulation are unlikely to be very effective instruments in controlling externalities we should use them only if absolutely necessary. The preliminary empirical analysis has indicated that implementation of IPM practices may reduce externalities significantly. Although we would still be required to levy a (pesticide) tax to fully internalize the external costs, the need to depend on this as a corrective instrument is much reduced. In other words, IPM, by directly tackling the externality aspect, minimizes our reliance on an input tax. Thus the case for recommending IPM practices is further strengthened. Although adoption of IPM is not an easy task, the fact that it has been successfully done in several parts of the world is a good indication that it can be successful in the present context also.

With reference to the special abilities of Heliothis armigera, two substantive issues come up. The first is to do with the existence of refugia, i.e., a reservoir of susceptible strains in unsprayed crops that help dilute the overall resistance of this pest. It was pointed out that unsprayed sorghum areas in Maharashtra were a important refugia but which were fast dwindling because of competition from oilseeds. Specifically, as per the recommendations of the "Technology Mission on Oilseeds and Pulses", the prices of oilseeds have beeen raised significantly to encourage their production. This has led to a large scale substitution, with the (mainly non sprayed) sorghum areas being given over to the cultivation of oilseeds. Clearly, if the resistance problem has to be managed on a macro level (as it must), interventions in the pricing of agricultural crops must take this into account.

The second issue concerns the propagation of the pest in the Guntur area. We have seen that because of continuous host availability, Heliothis armigera propagates itself throughout the year. It is very important to convince farmers to go in for summer fallows because this will break the pest cycle and keep the pest populations in check. This can be done via education and awareness creation so that farmers are persuaded to see the long term benefits and are willing to sacrifice short term gains for future profits.

## Suggestions for Further Research

It is not intended that this report convey an alarmist message. Nevertheless, it appears that a dangerously high level of pesticide resistance has become a feature of AP cotton and worse, appears to be spreading to other parts of India. This implies that, to manage resistance at below economically damaging levels, resistance management programs should be designed and implemented on an urgent basis.

In order to do this efficiently, we need to improve our understanding of farming systems, especially the interlinkages between crop protection and pest management. In the process of presenting a preliminary empirical analysis of the problem for Guntur cotton, this report has also highlighted several areas where knowledge is limited and needs to be augmented and where it is almost non-existent and new research needs to be initiated. In the following paragraphs, we shall mention the areas requiring research on a high priority basis.

First, resources should be devoted to extending the resistance monitoring program (as of now it is largely confined to ICRISAT and the Lam farm at Guntur) so that there is round-the-year monitoring for different crops and different areas. This should enable us to estimate pest population equations, migration equations, etc. and to isolate the most important determining factors for each. More extensive monitoring studies will also help in getting a better idea of the migration patterns and consequently of the affected areas which are distant from Guntur. The aim would be to analyse resistance data in conjunction with crop yield data (for Guntur and other areas) in order to estimate the relationship between resistance and crop damage and thus obtain estimates of the externality costs, of the sorts described in Section VII. Continuing crop damage studies will also enable the identification of realistic values of Economic Thresholds and thus determine if and when changes in threshold values are necessary. Note that this aspect of the research would require collaboration between entomologists and economists.

Second, research needs to address the quantification of the direct environmental costs from pesticides, mentioned in Section IX. Among other aspects, this could provide information for decisions on managing or phasing out the environmentally most harmful pesticides.

Third, research is needed to examine the structure of the pesticides industry, with a special focus on the role of the "non standard" brand of pesticides and their formulators and of the role of pesticide retailers as de facto pesticide usage "experts"in influencing farmer decisions. The possible participation of the industry in setting up scouting services for an IPM program should also be addressed.

Next, it would be helpful to gather data on costs of production across as wide a variety of cotton farmers as possible. The aim of this would be to estimate the demand and supply elasticities for cotton and consequently, to estimate the the potential changes in cotton prices arising as a result of instituting corrective policies to take care of the externalities. In addition, this information can give us a better idea of the competition between cotton and other crops so that the substitution effects (as mentioned in Section X) can be accounted for. (Note that this information is likely to be useful if cotton export and import restrictions continue to be in effect in India. As pointed out in Section X, with no quantitative restrictions on trade in cotton it would be redundant to predict price changes as a result of changes in domestic policies since these will move up and down with world prices and the exchange rate. Knowledge of domestic demand and supply functions could, however, enable us to get an idea of the changes in the quantity of domestic cotton production and in cotton exports/imports).

Finally, more information is needed on the socioeconomic profiles of farmers in order to design an efficient means of disseminating IPM techniques. This should also help in designing a workable scouting program, which is key to the success of an IPM approach.

# APPENDIX 1

In a usual regression analysis with either aggregate output or yield as the dependent variable, the independent variables thought to have an important influence are--a vector of agricultural inputs including seeds, water, fertilizers and pesticides, a vector of weather variables including rainfall, humidity, number of rainy days and temperature and a vector of pest related variables including a resistance index and pest population and finally, time as an index of technological progress. However, if our objective is to predict the losses due to pests for certain years, then we should include neither the observations for those years, nor variables such as resistance, pest population and pesticide use, all of which will directly influence pest damage. Additionally, the process of curve fitting that we have followed is to find the line of best fit (using the "normal" data points), with parsimony in the choice of independent explanatory variables (Maddala, 1988). These requirements clearly indicate that the smallest number of independent variables be chosen from the above mentioned list of potential candidates. Thus, by regressing output on acreage under cultivation, time and the square of time we obtained an $R^2$ of 0.94. Since only three explanatory variables have been used, this fulfilled our objective of economy in parameterisation. Furthermore, the explanatory power of this equation, at 94%, made us confident that the omitted variables problem was not a serious one. As stated in the text, this was the equation used for damage calculations.

The best fitting equation, when yield was used as a dependent variable and time as the independent variable, gave an $R^2$ of 0.70. Thus a large proportion of the variation in yield is left unexplained. Nonetheless, the damage estimates based on this equation were extremely close to those obtained from the "aggregate output" equation, being 60% from the "yield" equation and 58.5% from the "aggregate output" one. This provides a valuable corroboration to our empirical efforts.

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